MODEL RIVER LIFT IRRIGATION
SCHEME FOR INDIA

by

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TABLE OF CONTENTS

TABLE OF CONTENTS ii

LIST OF TABLES iii

LIST OF ILLUSTRATIONS iv

INTRODUCTION 1

PURPOSE OF INVESTIGATION 3

REVIEW OF LITERATURE 5

CLIMATES, SOILS AND CROPS OF INDIA 27

DESIGN OF THE SYSTEM 39

ECONOMIC DISTRIBUTION SYSTEM DESIGN 50

DISTRIBUTION SYSTEM DESIGN ON THE BASIS OF
MATERIALS AVAILABLE IN INDIA 60

COST ANALYSIS 66

CONCLUSION AND RECOMMENDATION 70

ACKNOWLEDGEMENT 72

REFERENCES 73

APPENDIX 76

LIST OF TABLES

1. Computed Normal Unit Consumptive Use of Water for Potato, West Bengal 6

2. Normal Seasonal Consumptive-Use Coefficients for the More Important Irrigated Crops of the Western U. S. 7

3. Percent Daylight Hours for India 8

4. Daily and Total Water Requirements for Some Common Indian Crops 9

5. Acre-Inches of Water Required for Rice in Different Countries 10

6. Time of Sowing and Harvesting in Case of Multiple Cropping Schemes in West-Bengal 13

7. Unit Fuel Consumption per Acre-Foot per Foot of Lift for Different Energy Sources 18

8. Average Monthly Total Rainfall of West-Bengal 29

9. Average Mean Monthly Temperature of West-Bengal 29

10. Water Holding Capacity of Different Textural Group of Soils 30

11. Important Moisture Characteristics of Typical Major Soils of India 32

12. Typical Crop Schedule for the Scheme 40

A_1. American-English-Metric Conversion Constants 77

A_2. Resistance of Fittings and Valves 78

LIST OF ILLUSTRATIONS

1. The average unit cost of water in cents per acre-foot per foot of lift for different energy sources 14

2. Water cost in dollars per acre-foot compared to annual hours of operation and total lift for diesel 16

3. Power unit investment cost versus water horsepower 17

4. Selection of economic pipe size from total annual cost 21

5. Chart for determining economic pipe diameters 22

6. Chart for friction head loss in asbestos cement pipes 25

7. Chart for friction head loss in asbestos cement pipes 26

8. Map of India showing different rainfall regions 28

9. Map of India showing different soil regions 31

10. Schematic layout of the economic distribution system 51

11. Schematic layout of the model distribution system 65

1_A. Resistance coefficients for pipe fittings 79

2_A. Calculating depth of water to be applied per irrigation 80

3_A. Relation between stream size, time of irrigation and depth of water to be applied 81

4_A. Installed cost per foot as a function of pipe diameter for irrigation concrete pipe 82

5_A. Installed cost per foot as a function of pipe diameter for asbestos cement irrigation pipe 83

INTRODUCTION

Food shortage has become an acute problem of India for the last few years. The shortage and the consequent import of food grains from outside is keeping the country's economy down. The continuous drought during the last few years has made the situation worse. The total production of food grain has been reduced from 88 million tons to 77 million tons during the last year. This is mainly because of failure of monsoon.

India, being an agricultural country, must reach self-sufficiency in food. The sooner it can be achieved the better for the country's overall economy. The present difficulties re-emphasize the need to concert and implement measures to increase the production of food grains in the shortest possible time. Only by the application of modern science and technology can agricultural production increase in an adequate measure. In the new agricultural strategy, greatest emphasis has been placed on the use of improved varieties of seeds which are particularly responsive to the application of fertilizers. Similar emphasis has also been given to speed up the irrigation projects.

With the population swelling year after year, irrigation has to have a new objective. This objective is to develop a comprehensive system of irrigation directed towards increasing production.

The total area of the Indian Union is about 813 million acres. Out of this about 334 million acres are cultivated every year. Roughly about 50 million acres are sown more than once. The total cropped area in the country, according to the land statistics of 1960-61, is about 385 million acres.

Before Independence, India had a yearly irrigated acreage of about 50 million. During the post-Independence period, roughly another 12 million acres have been brought under irrigation. This means that only about one fifth of

the total cropped land is served by irrigation of one kind or another. The prevailing irrigation systems of India can be placed in three categories: (i) diversion weirs and canals; (ii) irrigation tanks and reservoirs; (iii) tubewells and surface percolation wells. Recently river lift irrigation schemes are gaining importance.

Out of 1,350 million acre-feet of water available from the surface resources of the country, only 76 million acre-feet were utilized for irrigation purposes until 1951. This was hardly five and one-half percent of the total annual flow of the rivers. Through the first, second and third Five Year Plans use of another 40 million acre-feet has been sought for irrigation purposes, leading to an overall utilization of about seven and one-half percent of the total flow.

Besides surface water resources, there is considerable scope in the country, more particularly in the alluvial tracts, for the development of ground water resources for irrigation. There were only 2,400 state tubewells in India in 1950-51. The number has been increased to 10,000 at present. The plan is to add another 700,000 tubewells to the present number during the fourth Five Year Plan.

The construction of several dams and barrages all over the country facilitates the use of surface water for irrigation through canal systems. Some amount of surface water is also being utilized through indigenous lifting methods. The construction of dams and barrages requires a huge capital investment and may not be feasible economically for each and every river. The vast amount of water left can be utilized for irrigation through separate river lift irrigation systems. The size of the scheme will depend on the water and land available near the river for this purpose.

The Government of West-Bengal had started these river irrigation projects a few years back. The two types of projects, type A and type B, irrigate 500 and 1,000 acres of land respectively. Since the available electric power is mostly used for the deep tubewells, the river lift irrigation schemes are run by diesel engines. One hundred seventy similar projects have already been installed and the work is under steady progress.

PURPOSE OF INVESTIGATION

The purpose of this report is to design a model 500-acre river lift irrigation scheme suitable for West-Bengal conditions. With little change in the design, the same can be used all over India. A suitable crop schedule was prepared considering double and triple cropping possibilities. The design discharge for the entire system was calculated considering crop consumptive use, rainfall and soil factors. The pump and the power unit should be selected on the basis of peak discharge which would occur during the different cropping periods in a year and the total head against which the water would be delivered. The economical pipe sizes of the main and laterals distribution was calculated on the basis of minimum total yearly cost. The prevailing price of the pipes in Kansas was used for this purpose. The distribution system was then redesigned on the basis of the pipes available in India at present. The total annual cost of the entire system was estimated for the Indian conditions. This would give an idea about the total expenditure involved and the revenue to be collected from the farmers coming under the scheme.

The scheme involves considerable investment and should be utilized properly. Although any specific design can not be used all over West-Bengal due to the variation of climatic and soil conditions, a model design would,

however, be helpful in carrying out any specific design with little change in cropping pattern. Almost all the crops which are grown in West-Bengal have been included in the model design so that any little change in the cropping pattern would not change the design discharge substantially. For the same reason a liberal value of crop consumptive use has been used in the design. The design would give a clear picture as to how many hours the pump should run during each period to cover the entire need of the crop. This would also help in designing a suitable cropping pattern and irrigation schedules.

REVIEW OF LITERATURE

Consumptive use of different crops to be grown in any irrigation scheme should be known to the designer for an accurate irrigation system design. Consumptive use, or evapo-transpiration, is the sum of two terms; (1) transportation, which is water entering plant routs and used to build plant tissue or being passed through leaves of the plant into the atmosphere, (2) evaporation, which is water evaporating from adjacent soil, water surface, or from the surfaces of the leaves of the plant. The evapo-transpiration is influenced by temperature, irrigation practices, length of growing season, precipitation, and other factors.

Among the different methods of measuring consumptive use, the method developed by Blaney and Criddle (14) is used most extensively.

By multiplying the mean monthly temperature (t) by the monthly percentage of day-time hours of the year (p), there is obtained a consumptive use factor F. Expressed mathematically, it is

$$U = K\,pt = KF$$

Where the following quantities must be determined for the same period:

U = consumptive use of crop; inches for a given time period

F = sum of the comsumptive use factors for the period (sum of the products of mean temperature and percent of annual day-time hours) or $(t \times p)/100$.

K = empirical coefficient (annual, irrigation season, or growing season)

t = mean temperature in degrees Fahrenheit

p = percent of day-time hours of the year, occurring during the period.

For monthly calculations lower case letters are frequently used for clarity as follows:

f = monthly consumptive use factors, (t x p)/100

k = monthly coefficient, u/f

u = kf = monthly consumptive use.

The consumptive use of water by particular crop in some area being known, an estimate of the use by the same crop in some other area may be made by application of the formula U = KF.

Table 1. illustrates use of this method to compute monthly consumptive use by potatoes in West-Bengal. The values for consumptive use coefficient and percent daylight hours have been taken from Table 2 and 3.

Table 1. Computed Normal Unit Consumptive Use of Water for Potato, West-Bengal.

Month	Mean monthly temperature of (t)	Day-time hours % (p)	Consumptive use factor (f)	Coefficient (k)	Consumptive use, inches (u)
October	81.0	8.09	6.55	0.9	5.90
November	74.0	7.40	5.47	0.9-	4.94
December	67.0	7.42	4.97	0.9-	5.98
January	67.1	7.53	5.05	0.9-	4.55
February	72.2	7.14	5.15	0.9	4.65
Total consumptive use for the season					25.53

The value is far below that obtained by Arakeri (1) in his experiments. This may be due to the difference in experimental technique.

Table 2. Normal Seasonal Consumptive-use Coefficients for the more Important Irrigated Crops of the Western U. S.

Crop	Length of growing season, months	Consumptive-use coefficients seasonal (K)	Maximum monthly (k)
Beans	3	0.65	0.75 - 0.85
Corn	4	0.75	0.80 - 1.20
Cotton	7	0.70	0.75 - 1.10
Citrus Orchard	7	0.60	0.65 - 0.75
Potatoes	3	0.75	0.85 - 1.00
Rice	3-4	1.00	1.10 - 1.30
Small Grain	3	0.75	0.85 - 1.00
Sorghum	5	0.70	0.85 - 1.10
Sugar Beets	5.5	0.70	0.85 - 1.00

Source: Criddle (14)

Table 3. Percent Daylight Hours for India.

Latitude 0° North	January	February	March	April	May	June	July	August	September	October	November	December
5	8.33	7.57	8.47	8.29	8.65	8.41	8.67	8.60	8.23	8.42	8.07	8.30
10	8.13	7.47	8.45	8.37	8.81	8.60	8.86	8.71	8.25	8.34	7.91	8.10
15	7.94	7.36	8.43	8.44	8.98	8.80	9.05	8.83	8.28	8.26	7.75	7.88
20	7.74	7.25	8.41	8.52	9.15	9.00	9.25	8.96	8.30	8.18	7.58	7.66
25	7.53	7.14	8.39	8.61	9.33	9.23	9.45	9.09	8.32	8.09	7.40	7.42
30	7.30	7.03	8.38	8.72	9.53	9.49	9.67	9.22	8.33	7.99	7.19	7.15
32	7.20	6.97	8.37	8.76	9.62	9.59	9.77	9.27	8.34	7.95	7.11	7.05
34	7.10	6.91	8.36	8.80	9.72	9.70	9.88	9.33	8.36	7.90	7.02	6.92
36	6.99	6.85	8.35	8.85	9.82	9.82	9.99	9.40	8.37	7.85	6.92	6.79
38	6.87	6.79	8.34	8.90	9.92	9.95	10.10	9.47	8.38	7.80	6.82	6.66
40	6.76	6.72	8.33	8.95	10.02	10.08	10.22	9.54	8.39	7.75	6.72	7.52

Source: Israelsen (14)

Arakeri (1) published the data on daily and total water requirement of some common Indian crops which are shown in Table 4.

Table 4. Daily and Total Water Requirements of Some Common Indian Crops.

Crop	Days of Experiments	Daily Water requirements acre-inches	Total Water requirements acre-inches
Mustard	88	0.12	10.6
Pea	88	0.14	12.0
Linseed	88	0.14	12.7
Barley	88	0.16	14.1
Oats	88	0.16	14.4
Wheat	88	0.17	14.8
Maize (Corn)	100	0.18	17.8
Chillies	202	0.19	25.7
Groundnut	124	0.21	26.1
Cotton	202	0.21	26.7
Jower	114	0.23	29.8
Ragi	127	0.23	38.8
Sugar Cane	365	0.26	39.2
Potato	88	0.30	41.7
Tobacco	132	0.30	42.2
Rice	98	0.43	95.0

Source: Arakeri (1)

Arakeri's (1) comments on rice cultivation gave some idea about water requirement of the crop. He says that the rice plant in the green stage contains

nearly ninety percent water. A continuous supply of water is necessary for the healthy growth of the plant.

In studies conducted under semi-field condition it was found that standing water suppressed the tiller formation of some varieties of rice. The number of tillers decreased with the increase in the depth of water. With short duration varieties flooding the field for three weeks after transplanting, with subsequent draining, was found to be feneficial in certain locations.

Water duty which is the number of acre-inches required by rice in different countries is shown in Table 5.

Table 5. Acre-inches of Water Required for Rice in Different Countries.

Country	Water duty (acre-inches required)
Japan	28 - 52
Thailand	92 - 72
Indochina	48 - 50
Ceylon	72+
New South Wales, Australia	72+
Louisiana & Texas, U. S. A.	48 - 60
California, U. S. A.	60 - 72
India	60 - 90

In Japan alternate drying and irrigation are practiced with very good results. Irrigation experiments conducted in India show that two inches of irrigation water at intervales of four days gave the best yield of rice.

Nester (20) in his circular on rice production in Arkansas reported that an ample supply of good quality of irrigation water is necessary for successful

rice production. About 33 inches of water are required to produce a rice crop. Of this amount, 20 to 24 inches usually are supplied by irrigation from wells, reservoirs or streams. In addition to normal rainfall about 540,000 to 650,000 gallons per acre are required during the growing season. The amount of water used in irrigating rice will depend on several factors including the amount and distribution of rainfall, humidity, temperature and evaporation, kind of soil and the watering practice followed.

Finfrock and others (7) mentioned, in brief, the water requirement of rice in California. They reported that after flooding, the water required to maintain a constant depth in the field would equal the sum of losses due to transpiration by plants, evaporation from the water surface, deep percolation and spillage.

The losses would vary from day to day and from one field to the next depending on plant growth, solar radiation, temperature, wind, relative humidity, soil type and rate of inflow of water into the field.

Total seasonal use would normally vary from 60 to 108 acre-inches of water for each acre irrigated. On deep, permeable soils, the irrigation water requirement might be two to three times this amount. Rice is normally not grown on such soils. A rate of flow equal to 1 cubic foot per second (450 U.S gallons per minute) for each 50 acres being irrigated would be required usually to maintain water levels on the field.

The discussion by Houston on the paper of water management on riceland in Louisiana and Texas by Lawhon (18) revealed some of the rice cultivation facts in California.

According to him the classical definition of consumptive use of water by plants should be revised in regard to the rice plant. The main difference in the amount of water required to grow rice as compared to upland crops is that

it is usually flooded from 90 to 100 days. There is a consequent evaporation loss from the free water surface with some deep percolation. Since the standard definition of consumptive use included evaporation from adjacent soil, perhaps the standard definition for rice consumptive use should include evaporation from adjacent water.

There is experimental evidence that rice yields are higher with shallower water (two to four inches) if weeds can be controlled chemically, than where water is held from six to eight inches deep.

Irrigation ditches serving rice fields are large enough to carry sufficient water to flood the field rapidly. On an average rice field a flow of about 12 to 16 cubic feet per second is required to flood 100 acres to an average depth of six inches in 96 hours. This is assuming that one foot depth of water is needed to prime the soil and cause the water to stand six inches deep in the checks.

Pandey (22) compiled the field experimental results on triple cropping with jute, rice, wheat, potato and pulses. Under West-Bengal conditions, where Jute is mainly grown, the most profitable cropping sequences were observed as jute and potato, jute and wheat, and jute, aman (lowland) rice and pulses. When jute is followed by aman paddy (lowland rice), the jute crop should be harvested by the middle of August. This one month earlier harvesting reduces the yield by 30 percent and causes tremendous amount of loss. Table 6 shows the timings which should be followed in case of double or triple cropping.

Table 6. Time of Sowing and Harvesting in Case of Multiple Cropping Scheme in Bengal.

Crops	Sowing time	Harvesting time	Water requirements
Jute (followed by aman paddy)	First week of April	Second week of August	Three to four irrigations up to middle of June, each time three acre-inches
Jute (followed by potato, wheat or other winter crop)	Middle of April	Middle to end of September	
Aus Paddy (followed by Aman Paddy)	Third week of April	Middle of July	Three to four irrigations at the interval of 10 to 15 days, each time three acre-inches
Aman Paddy	Middle of August	End of November	
Pulses (Lentil or Pea)	First week of December or in standing paddy 15 to 20 days before harvest	Middle of March	Generally no irrigation required. In case of need one irrigation with three acre-inches are given

Hanson (11), in master's thesis, investigated irrigation pumping costs and annual hours of use for different types of fuel and energy sources. The cost relationships developed are shown in Fig. 1. These costs were based on the prevailing prices. Hanson also computed the overall efficieny of the plant from energy input and water horsepower output. The average value was 16.88 percent for diesel and 52.9 percent for electricity.

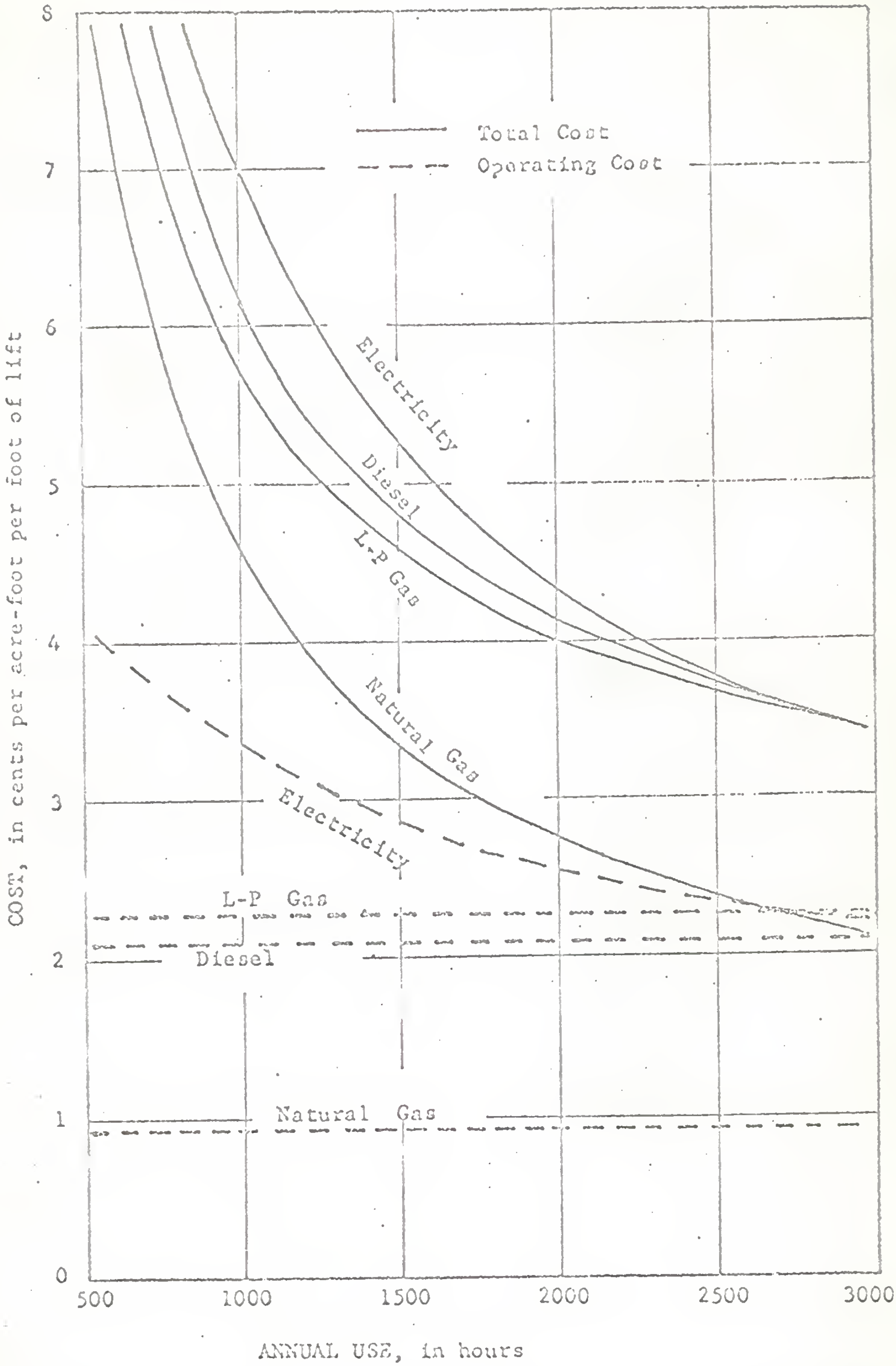


Fig. 1. The average unit cost of water in cents per acre-foot per foot of lift for different energy sources. Source: Hanson (11)

Dickerson and others (6) correlated irrigation water costs with total pumping lift using most of the same data that was used by Hanson. Figure 2 shows the same relationship for diesel fuel which is commonly used for pumping water for irrigation in India. They asserted that to obtain maximum profit, the design of the irrigation operations should be for a maximum operating time of the pumping unit. This is because the fixed costs per acre-foot go down as more water is pumped, while operating costs per acre-foot remain about the same regardless of operating time.

Nuzman (21) estimated and compared the cost of electric and internal combustion units. Power unit costs vary with the horsepower and with the energy source. The initial cost of an electric motor is normally less than the equivalent internal combustion engine, but usually has a higher operating cost. Electric motors can be operated at a power demand equal to the rated power, but engines operate at a power load of less than approximately 70-80 percent of the rated power. The right-angle gear drive's costs are included with the cost of the engine. The initial investment power cost for the water horsepower required are shown in Figure 3.

The investment cost of an internal combustion engine for all fuel sources can be estimated from the following relation:

$$I_e = 1517 + 39.44 \text{ Whp}.$$

Where I_e is the engine investment cost in dollars, and Whp is the water horsepower obtained from equation Whp = QH/3956 (Q in gpm and H, head, in feet).

The investment cost of an electric motor can be estimated from the following relation:

$$I_k = 341.30 + 23.29 \text{ Whp}.$$

Where I_k is the initial investment cost in dollars, and Whp is the water horsepower.

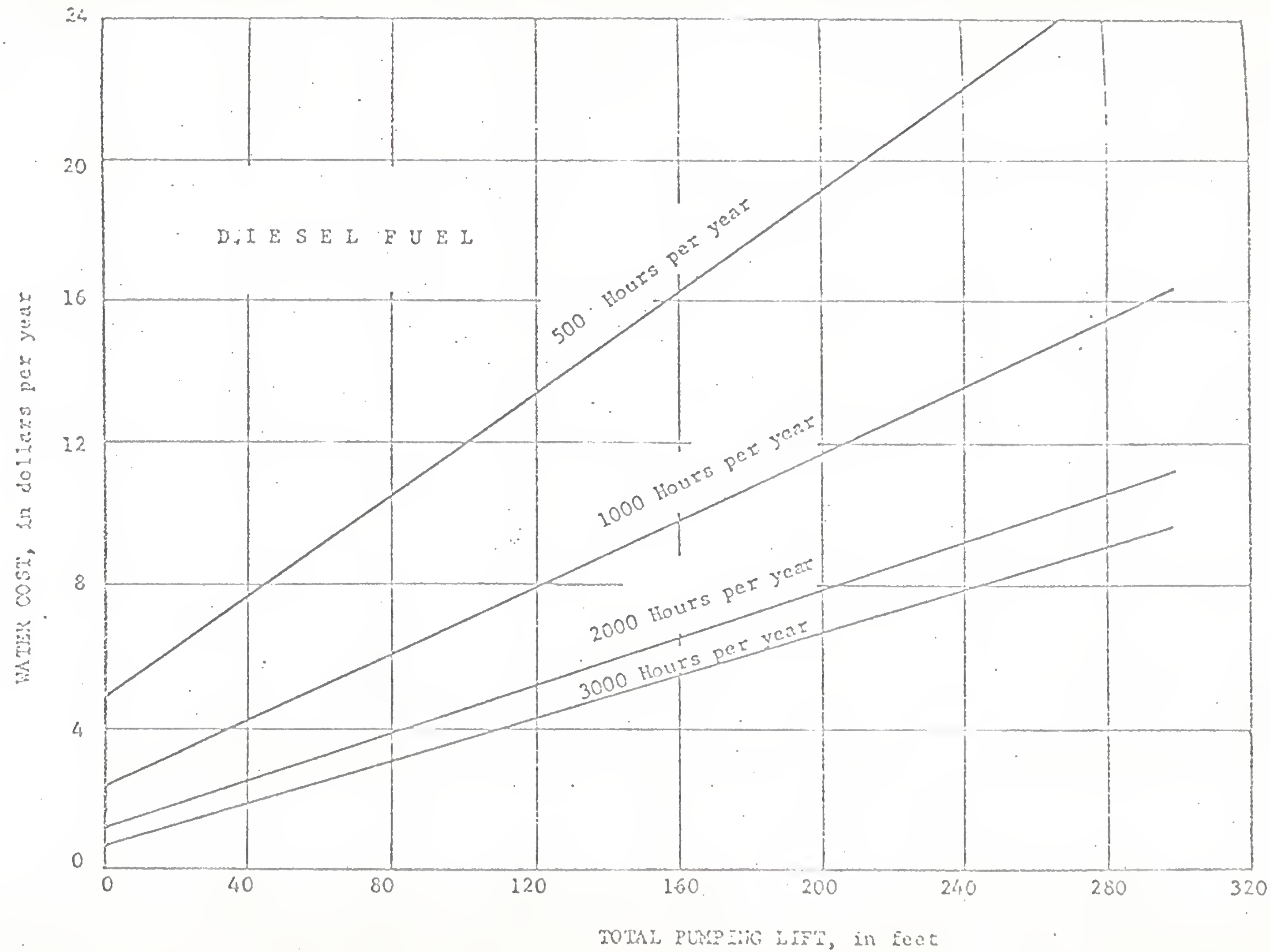


Fig. 2. Water cost in dollars per acre-foot compared to annual hours of operation and total lift for diesel. Source: Dickerson and others (6)

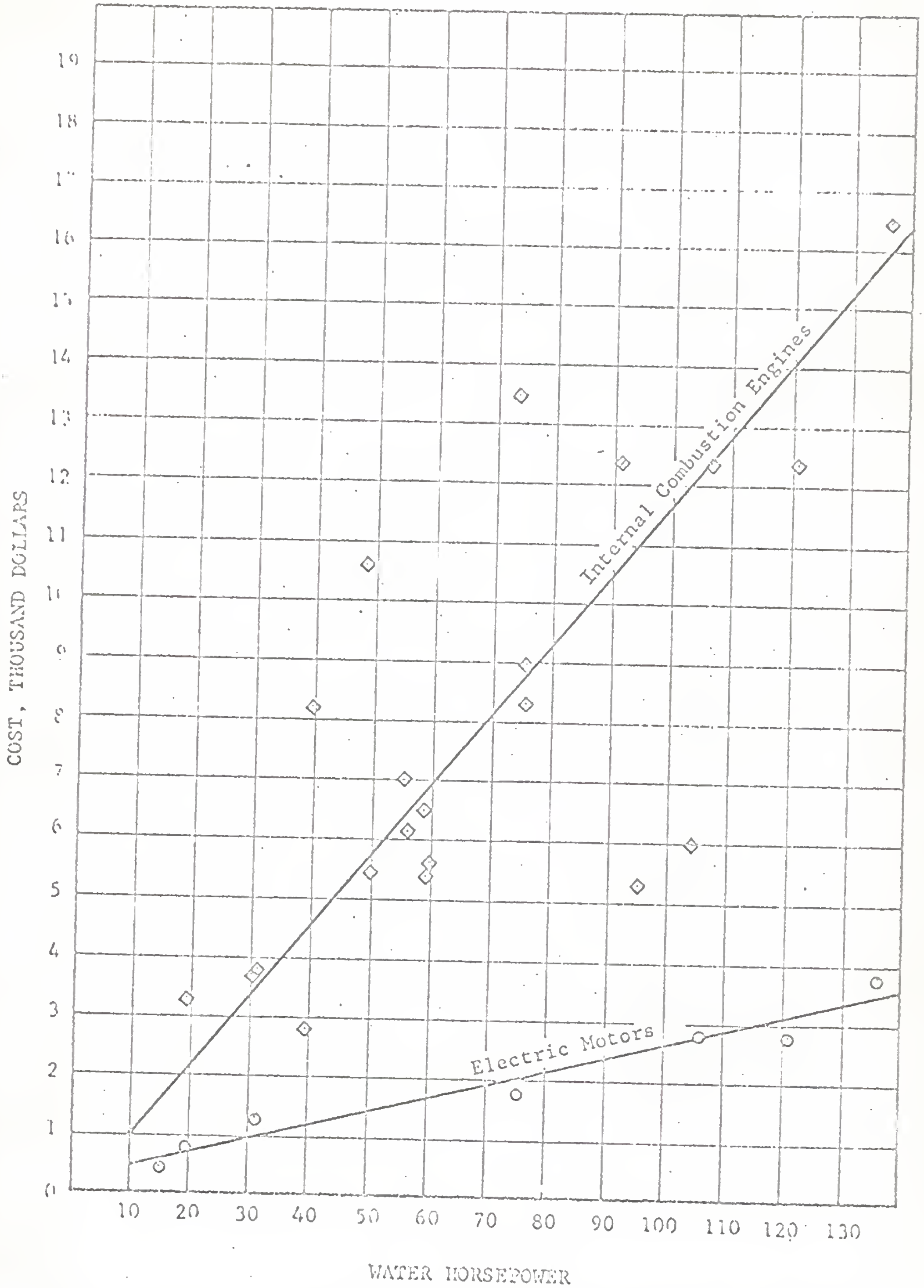


Fig. 3. Power unit investment cost versus water horsepower. Source: Hanson (11)

Diesel, liquified petroleum gas, natural gas and electricity are the main energy sources used for irrigation in the U. S. A. The range of fuel units consumed per acre-foot per foot of lift are shown in Table 7.

Table 7. Unit Fuel Consumption per Acre-Foot per Foot of Lift for Different Energy Source.

Energy Source	Units Consumed per Acre-Foot per Foot of Lift
Diesel Fuel	0.12 to 0.16 gallon
L-P Gas	0.21 to 0.27 gallon
Natural Gas*	21 to 29 cubic feet
**	24.8 to 38.4 cubic feet
Gasoline *	0.16 to 0.20 gallon
**	0.20 to 0.41 gallon
Electricity*	1.55 to 1.92 K.W.H.
**	1.55 to 2.48 K.W.H.

*Source: Hanson (11)

**Source: McCall and Davidson (21)

Depreciation of the pumping equipment has been most commonly calculated by the straight-line method which assumes that the decline in value of the installation was the same during each year of its usefulness or service life. Except in special cases, depreciation schedules commonly used ranged from 10 to 15 years for pumps, 20 to 25 years for electric motors, and from 5 to 15 years for internal combustion engines. Depreciation makes up the largest percentage of the ownership cost.

The interest charged on the average investment or depreciated value has most commonly been five or six percent. When equipment is depreciated by the

straight-line method, the average investment is equal to one-half the initial cost.

Taxes and insurance have generally been found to be a small item in the total cost of pumping.

The total unit pumping costs have been found to be primarily affected by the factors which cause variations in ownership costs and operating costs. Regarding the variation in total costs per acre-foot of natural gas plants from \$5.65 to \$17.10 and of electrically-operated plants from \$5.75 to \$23.30, Rehnberg (12) concluded that three factors were found to be closely associated with these variations. In order of importance they are the total distance that the water was lifted, the efficiency of the pumping unit, and the number of hours the unit was operated during the year.

According to Turneaure (27), if the loss of head is not fixed, as is the case where the pressure is supplied by the pumps, the size of pipe should be such as to make the toal yearly expenses minimum. From the known and assured rate, the cost of various sizes of pipe are calculated and the corresponding losses of heads are determined. The total yearly expense would then be the interest and depreciation charge on the conduit and the yearly cost of pumping. The economical size of conduit is that which makes the sum of these a minimum. The problem is illustrated graphically in Fig. 4. The annual cost per foot for various losses of head is represented by line AB; the annual cost of pumping per foot of conduit is represented by CD, which will vary little from a straight-line. The sum of the ordinates of these two curves are shown by EF, the low point of which at T will give the economical loss of head OX. From the economical loss of head, economical pipe size would be known.

Hicks (12) reproduced a chart from Chemical Engineering Handbook while

explaining how to select an economical pipe size in a pumping system when the liquid flow rate and density are known, and turbulent-flow exists. The same chart was reproduced again in Fig. 5. A similar chart can be developed for an irrigation system on the basis of existing cost of piping.

Horn (13) suggested the following method of calculating economic pipe size: The unit cost-diameter relation was first found out on the basis of market price. From this the annual total ownership cost of pipe was calculated. The water horsepower and then brake horsepower were then calculated in terms of diameter of the pipe from the total head and discharge involved. The total annual operating cost was also calculated in terms of diameter of the pipe. The final relation became as follows:

Total annual cost = annual ownership cost of pipe
+ annual ownership cost of pump and engine
+ annual operating cost

or

$$T_C = f_p\,(d) + f_{p,\,e}\,(d) + f_o\,(d).$$

Differentiating the above relation and equating to zero, the economic pipe size was calculated.

Horn also developed an equation for unit-cost diameter relationship of concrete pipe in the form

$$Cp = 0.77d^{1.16}$$

where Cp = cost per foot for a given diameter
d = diameter in foot.

The same relationship was reproduced in Fig. 4A.

The unit cost diameter relationship for asbestos cement pipe was developed as

$$C_p = 3.3d^{1.42}$$

This is shown in Fig. 5A.

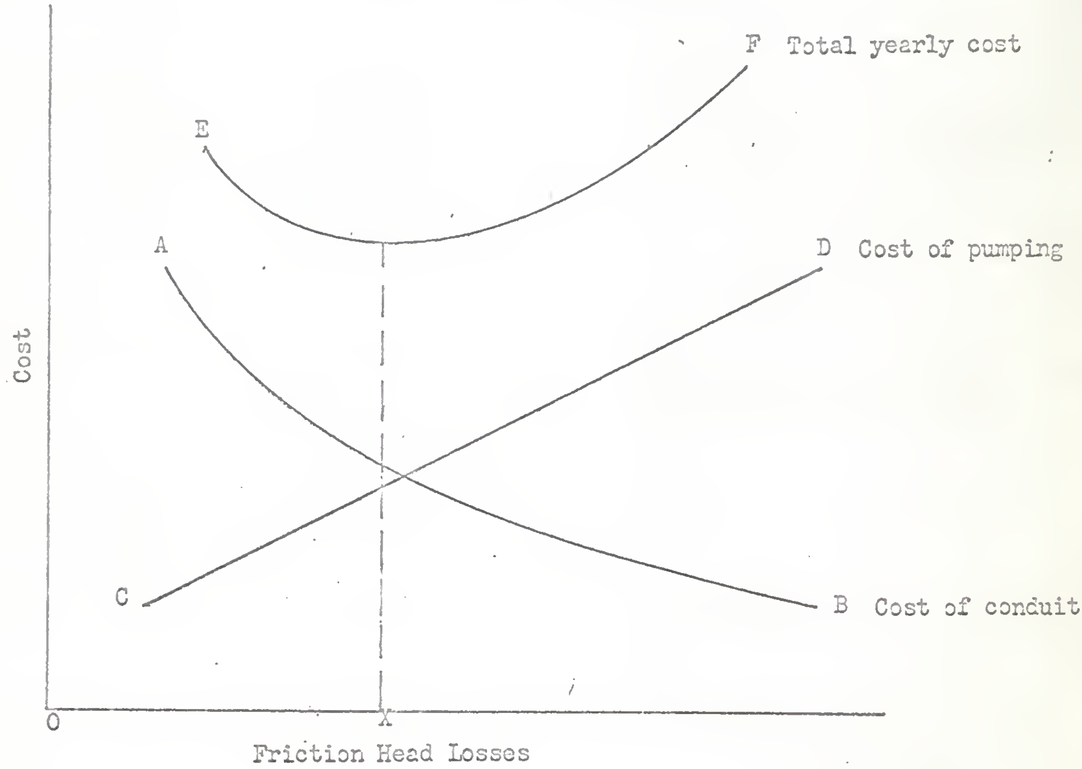


Fig. 4. Selection of economic pipe size from total annual cost.

Source: Turneaure (27)

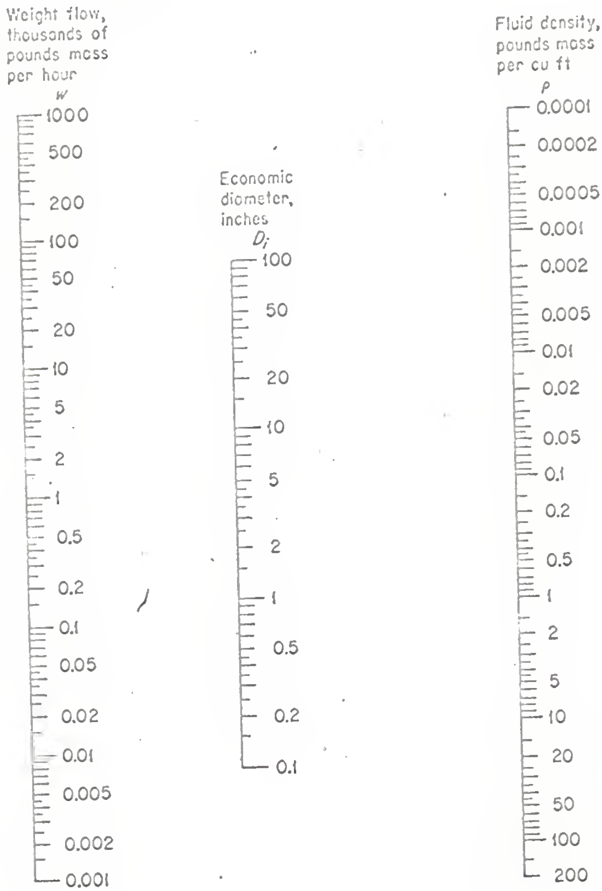


Fig. 5. Chart for determining economic pipe diameters. Source: Perry, Chemical Engineers' Handbook (12)

There are several formulae and charts (15) for the calculation of friction loss in a pipe. A few of the most commonly used ones are listed below.

(i) Chezy's formula: This represents the first successful attempt to express loss of head due to friction in algebraic terms. The modified form of the formula is

$$H_1 = f \frac{lv^2}{d2g}$$

Where H_1 is the head loss in feet for l feet of pipe

v is the velocity in feet per second

d is the diameter of pipe in feet

l is the length of pipe in feet.

For new, clean cast iron pipe

$$f = 0.02 + \frac{0.02}{12d}$$

For old cast iron pipe

$$f = 0.04 + \frac{0.04}{12d}$$

(ii) Scobey's formula: This is a widely used formula. It has different forms for different materials.

(a) for concrete pipes

$$H_f = \frac{V^2}{C_s{}^2 di^{1.25}}$$

in which H_f = loss of head due to friction in 1,000 feet of pipe

di = inside diameter in inches

C_s varies from 0.267 to 0.370 for the roughest to the smoothest surface.

(b) for riveted steel pipe

$$H_f = K_s \frac{v^{1.9}}{d^{1.1}}$$

Where K_s varies with the roughness of the pipe from 0.32 to 0.52 for new pipe

and from 0.50 to 0.80 for pipe after 30 years of use.

(iii) Williams and Hazan formula:

$$v = 1.318C_1 \, r^{0.63} \, s^{0.54}$$

Where r = mean hydraulic radius = $\frac{d}{4}$

s = loss of head per foot

Rearranging, the head loss per 1,000 feet becomes

$$H_f = \frac{3020-}{C_1 1.85} \times \frac{v^{1.85}}{d^{1.168}}$$

The following are the values of C_1 for pipes:

Extremely smooth and straight pipe, $C_1 = 140$.

Very smooth pipes, $C_1 = 130$.

New riveted steel pipes, $C_1 = 110$.

Certain-Teed Products Corporation has developed a chart for friction losses in asbestos-cement pipe for various flows and diameters of pipes based on Williams and Hazan formula ($c = 140$). These are reproduced in Fig. 6 and 7.

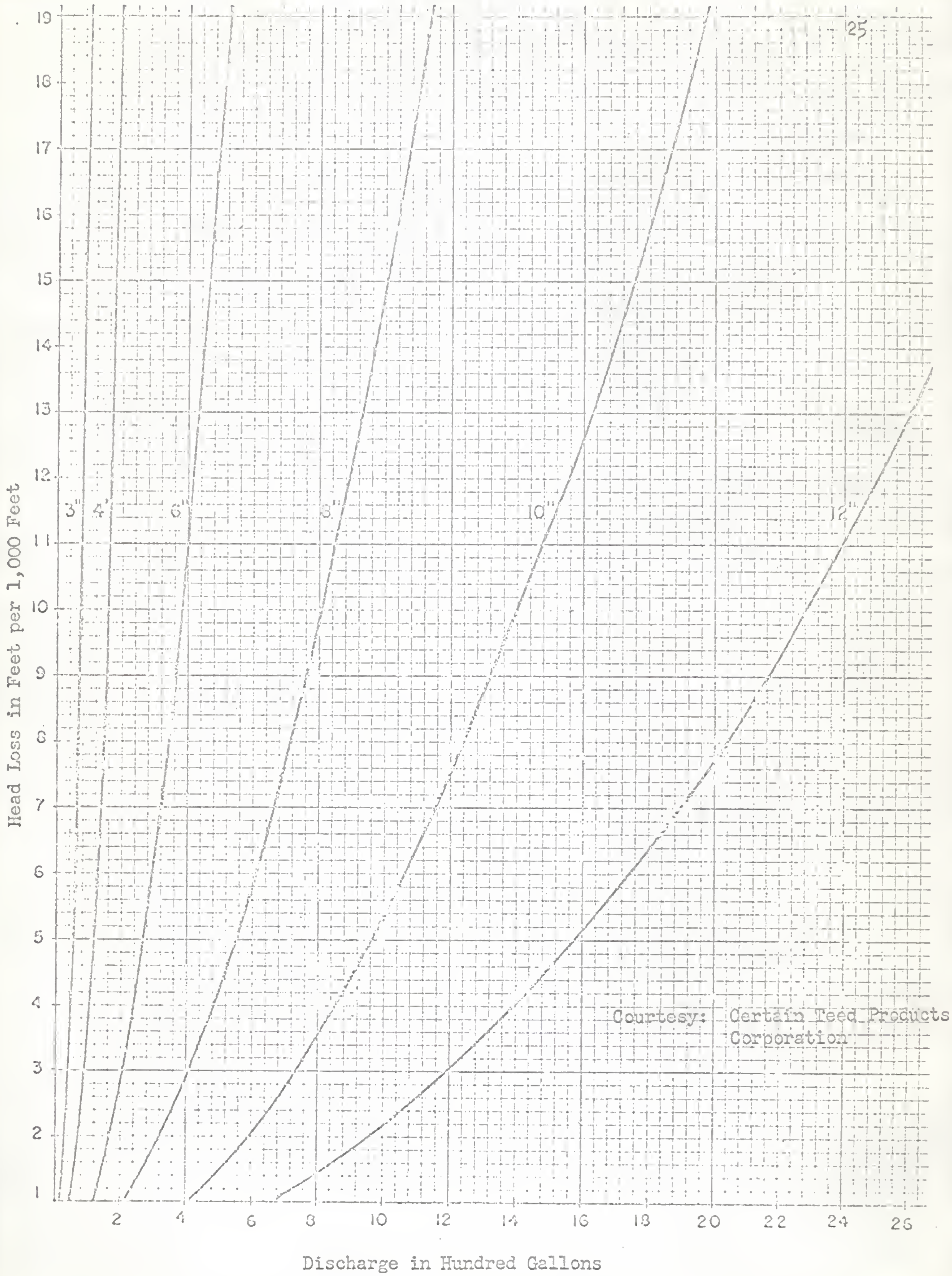


Fig. 6. Chart for friction loss in asbestos-cement pipe.

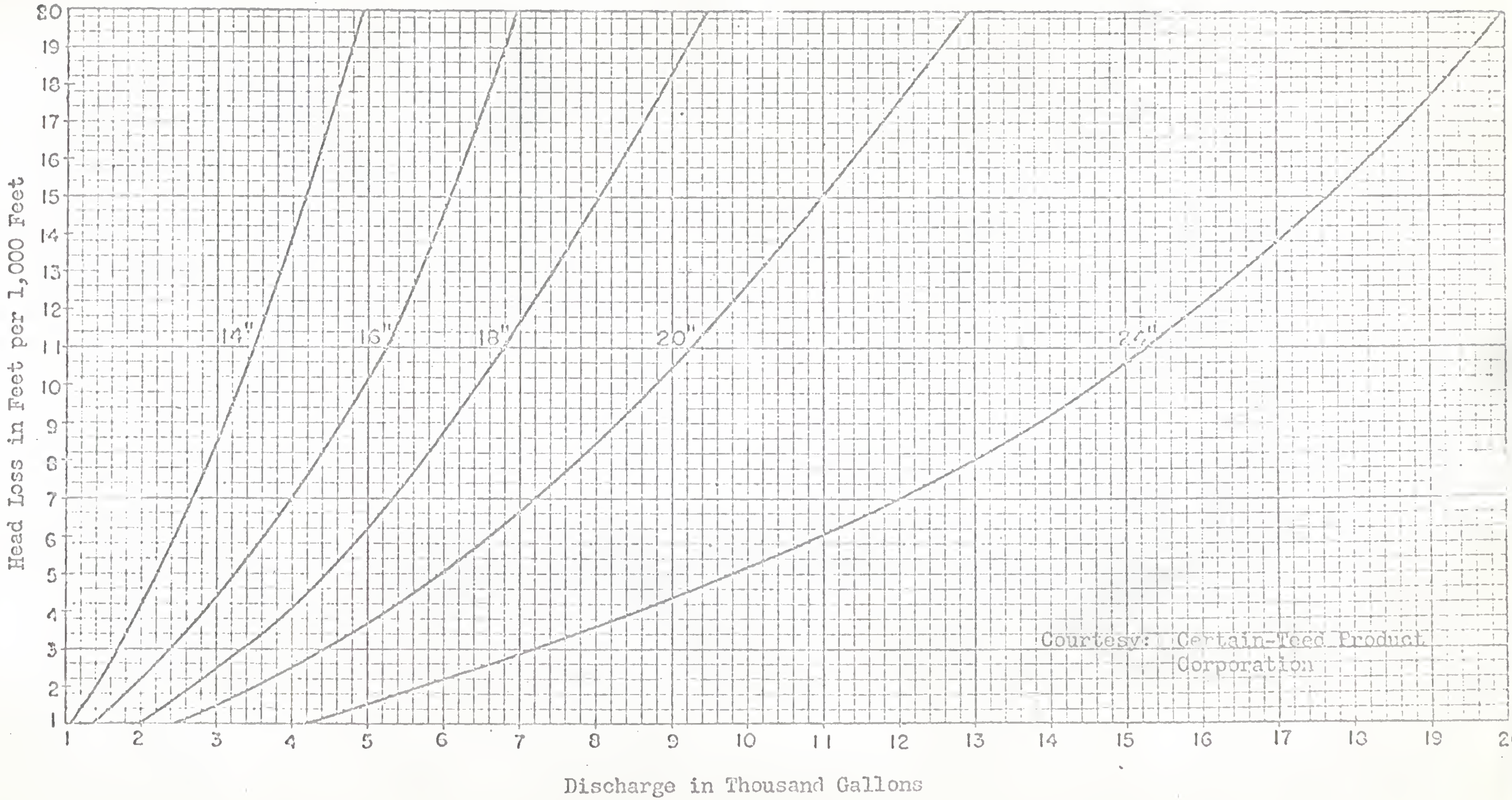


Fig. 7. Chart for friction head loss in asbestos-cement pipe.

CLIMATES, SOILS AND CROPS OF INDIA

Climates of India

The climate of India is intensely interesting to study because of the great contrast from season to season. India's climate is the best large-scale example of the alternation of seasons known as monsoons. The average annual rainfall varies from five inches in the desert of Rajputana to 430 inches on the hills of Cherrapunji. Temperature varies from -49°F to 126°F.

Rainfall takes place in India during the southwest monsoon because the air mass comes from warm, moist area over the Arabian Sea and the Bay of Bengal. Southwest monsoon starts towards the end of May, fully developed by the end of June and ends by October. On an average it give about 43 inches of total rainfall. Fig. 8 shows the different rainfall regions.

During the northeast monsoon some rainfall occurs only in South India (Madras). The air when flowing over the Bay of Bengal picks up moisture and causes rainfall. It gives about 20 to 30 inches total rainfall in Madras. This is beneficial for winter crop.

In Bengal rainfall generally occurs during the Southwest monsoon. It starts from the beginning of June and ends by October. On an average it gives about 30 to 80 inches of rainfall. Table 8 shows the average rainfall of Bengal. Table 9 gives the mean monthly temperature of Bengal as recorded in Calcutta.

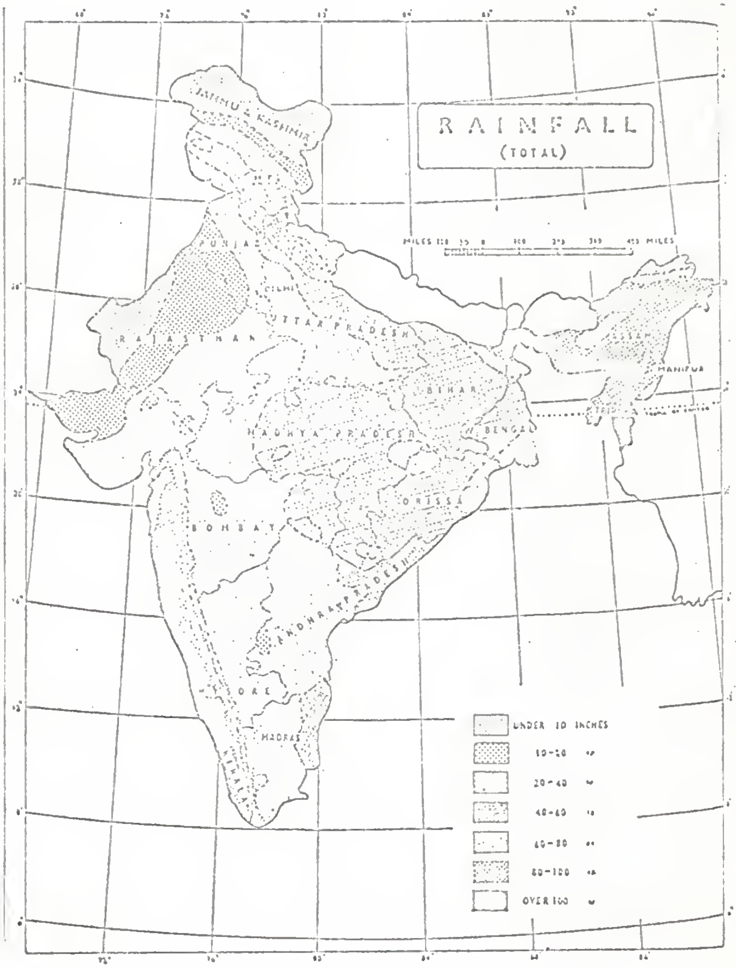


Fig. 8. Map of India showing different rainfall regions.

Source: Arakeri (1)

Table 8. Average Monthly Total Rainfall of West-Bengal.

Months	January	February	March	April	May	June	July
Average total rainfall in inches	0.62	1.60	0.63	1.50	3.70	7.40	12.40

Months	August	September	October	November	December	Yearly Total
Average total rainfall in inches	9.20	12.40	5.40	0.10	0.00	54.33

Source: Haldar (10)

Table 9. Average Mean Monthly Temperature of West-Bengal.

Months	January	February	March	April	May	June
Average mean monthly temperature °F	67.1	72.2	80.6	86.2	86.5	85.6

Months	July	August	September	October	November	December
Average mean monthly temperature °F	84.0	83.6	84.0	81.0	87.0	67.0

Source: Times of India (26)

Soils of India

In India, there are four major soil types; namely, alluvial, black, red and laterite extending over 300,000; 200,000, 200,000 and 49,000 square miles respectively. Fig. 9 shows the distribution of these soils over India. Bengal's soils are mostly laterite and red.

Texture, structure and organic matter content are the basic important characteristics of a soil influencing soil-water relationships. As alluvial soils are transported, these show a full spectrum of variation in texture and can be anything from sandy to clay in texture. A black soil varies from fine sandy clay to clay. The red soils are generally sandy loam to clay loam in nature while laterites vary from sandy loam to clay. Water holding capacities of different textural groups are shown in Table 10.

Table 10. Water Holding Capacities of Different Textural Group of Soils.

Textural Class	Available water holding capacity per foot depth of soil inches
Sandy	0.25 to 0.75
Loamy Sand	0.75 to 1.25
Sandy Loam	1.00 to 1.50
Fine Sandy Loam	1.50 to 2.00
Clay Loam	1.75 to 2.25
Clay	2.00 to 3.00

Source: Criddle (5)

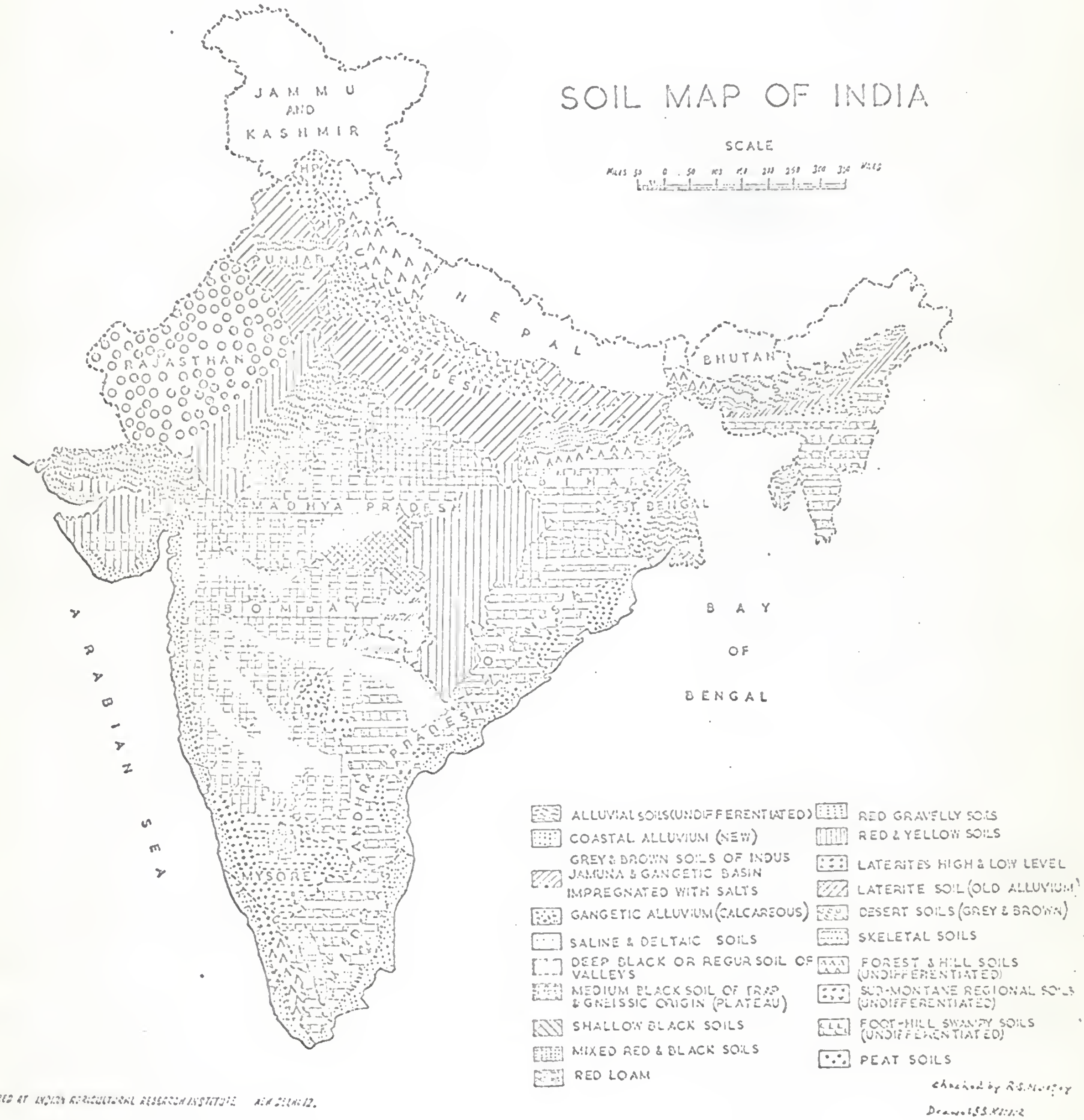


Fig. 9. Map of India show different soil regions

Source: Arakeri (1)

A comparative statement of mechanical analysis of different soils is presented in Table 11.

Table 11. Important Moisture Characteristics of Typical Major Soil Types of India.

Soil Group	Percent Fraction of Surface Soil: Coarse Sand	Fine Sand	Silt	Clay	Textural Class
Alluvial Soil (Kanpur)	0.23	57.8	25.7	14.1	Sandy Loam
	1.50	36.3	27.9	27.8	Loam
	2.0	72.1	14.5	8.4	Loamy Sand
Black Cotton Soils (South India)	0.7	11.4	21.8	45.2	Clay
	18.9	13.5	16.1	47.4	Clay Loam
	41.2	18.2	11.4	23.9	Sandy Loam
Laterite and Red Soils (Bengal)	10.0	43.0	20.0	27.2	Sandy Loam
	32.0	19.3	18.0	32.3	Loam
	24.0	27.0	31.2	18.0	Sandy Loam

Source: Handbook of Agriculture, Indian Council of Agricultural Research, New Delhi, 1961 (5).

Crops of India

According to the season there are two types of crops in India; namely, Kharif (summer) and rabi (winter). The following gives a brief description of some of the Kharif and Rabi crops grown in Bengal:

Kharif (summer) Crops

Rice (oryza sative)

Rice grows in a variety of soils provided water is available and temperatures are warm. It does best on medium textured soils with a clay substratium.

In general the systems of rice production can be divided into three headings--dry system, semi-dry system and wet system.

The dry system of rice production is very widely practice in humid areas where there is no possibility of getting irrigation water and where rainfall is not sufficient for adopting the semi-dry and wet systems of cultivation. The semi-dry system of rice production is followed in medium rainfall tracts, in low laying areas in low rainfall tracts, and in areas where irrigation water becomes available at a little later stage. Sowing is done quite early with the arrival of the first pre-monsoon showers in the month of April, May, or June. By the time the seedlings are eight to ten inches high, rain is usually received to enable the impounding of water in the field. In the wet system of rice production, seedlings are raised in seed beds under the dry, semi-dry or wet systems and then transplanted in the fields.

A continuous flow of water is maintained in the rice field during the latter part of the semi-dry system and during the entire period under wet system of rice production so as to keep the fields flooded mainly because of healthy growth and partly because of weed control. Experimental results have shown that it is usually sufficient to apply two-acre inches of water at intervals of four days.

From the earlier discussion it is evident that consumptive use of rice is not the same for all varieties of rice. This is due to the fact that their cultural practicies are not the same. During the first part of the semi-dry system when the fields are not flooded, the term consumptive use of rice is the same as used for other crops. During the latter part of the semi-dry system and for the wet system when the fields remain flooded, the definition of consumptive use of rice should be modified as indicated by Houston on page 11.

As indicated by several research workers, the classical definition of consumptive use of crops is not perfectly suited for rice. The concept is not yet

clear and definite values for consumptive use of rice under different systems of cultivation are not known.

The wet system is followed where the rainfall is plentiful and during the heavy rainy periods. The irrigator will be mainly concerned with the other two systems of cultivation. Under these systems, the consumptive use value is assumed to be a little less than that given as there is no evaporation from water surface. The three varieties of paddy--Aus (upland, broadcasted), Amau (lowland, transplanted) and Boro (winter) are commonly grown in West-Bengal. They are planted during the month of April, September and January respectively. The above time of sowing can be changed if irrigation water is available. Rice crop takes generally three to four months to mature. Some upland rice varieties can be harvested within two months.

Jute (Corchorus Capsularis and Corchorus Olitorius)

Jute is cultivated on deep, fertile, alluvial soils which become silted by floods almost every year. It can grow on any type of moderately good soil except gravelly, and lateritic soils. Jute needs a warm and humid climate. The jute-growing tracts receive an annual rainfall of 50 to 70 inches, mostly during March to October. The temperature during the growing period is above 83° F, and in the cold months it is between 68° to 75° F.

Jute can not be grown continuously on the same soil. On soils that do not flood, one of the following crops can be grown in rotation with jute: rice, wheat, oats, barley, pulses or tobacco. In flood-affected areas of low-lands, only rice can be grown in rotation with jute.

Jute requires about three to four irrigations up to the middle of June. It may be given at intervals of 20 to 30 days depending upon the soil conditions with three acre-inches of water per application.

Sugar Cane (Saccharum Officinarum)

Sugar cane is quite adaptable to varying soil conditions. It can be grown successfully in sandy or clay soil and in slightly acid to alkaline soils. Loam soil with good drainage is best suited for this crop.

Sugar cane is grown under a wide range of rainfall conditions, varying from fifteen to one hundred fifteen inches a year. It grows best in tracts having twenty to forty inches of rainfall, supplemented by timely irrigation. A growing season of ten months with adequate soil moisture followed by a dry winter, are the best conditions for higher yields. In Northern India, the best planting months are February and September. September plantings usually give higher yields. The common planting months in Southern India are January, February or July. Sugar cane planted in July remains in the field from twelve to twenty months, and that planted in January or February remains only from eleven to thirteen months.

The total water requirement of sugar cane is about one hundred inches per year. When the crop is grown regularly under irrigation, one irrigation before planting and one a few days after planting are given to insure proper germination. Subsequent irrigations are given at intervals of eight to twelve days, depending upon the type of soil and the season. At each irrigation, about two and one-half to three acre-inches of water are applied. In Northern India and in heavy rainfall tracts of Southern India only two to five irrigations are usually given.

Red Gram (Arahar) (Cajanus Cajan)

Red gram can be grown in almost any kind of soil. Well-drained alluvial, loamy soils are particularly suitable for this crop.

Red gram is grown as a pure crop and also as a mixed crop under rain-fed

conditions. No irrigation is required. Sowings are done during June and July. It requires about seven to eight months to mature and is harvested during the month of September-October.

Rabi (Winter) Crops

Wheat (Triticum Sativum)

Wheat produces higher yields on fertile, fine textured soils. As a dry land crop it grows best in clay soils. Under irrigation it can be grown even on sandy soils.

Wheat is grown during the dry, cool, winter months. Sowing is done at the end of October after the heavy showers are over. It matures in about three and one-half to five months.

The economic dosage of irrigation water for wheat is about ten to fifteen acre-inches of water at each application of four or five times during the growing season. Usually this gives good results.

Tobacco (Nicotiana Tobacum)

In dryland farming areas with medium rainfall, tobacco requires a clay soil that holds adequate moisture. When irrigation water is available, however, loamy and sandy soils are suitable.

Tobacco is a rabi (winter) crop and is planted during the month of October. It takes about four months to mature and is harvested during the month of January and February.

Immediately after transplanting, tobacco should be irrigated every three or four days for about two weeks and once a week thereafter.

Potato (Salanum Tuberosum)

The potato is a rabi (winter) crop in the plains and a Kharif (summer) crop in the hills. In the plains it is generally planted during the months of September to November and harvested during the months of February to April. Thus, it takes about six months to mature.

Potatoes can be grown in alsmost all soils except saline and alkaline ones, but are grown best in sandy loam that is rich in humus. Since the potato is very sensitive to excessive moisture, clay soils should be avoided. Potato should be rotated with some leguminous or green manure crop.

Bengal Gram (Cicer Arietinum)

Alluvial soils are the best for gram. It also can be cultivated in black soils which retain the sub-soil moisture. Gram is a cool season crop. It is grown as a single crop or as a mixed crop with wheat, millets, pulses or oil seeds. Sowing is done during the month of October and November. It is harvested within three to three and one-half months. Gram generally does not require any irrigation. Where the soils are dry, a light irrigation is given, taking care not to flood the field.

Lentil (Masur) (Ervem lens)

Lentil grows well in alluvial soils and black soils. It is even suited for soils of low fertility and slight alkalinity. It is cultivated under rain-fed conditions and, like gram, the crop thrives on sub-soil moisture. In some places a light irrigation is given.

Lentil is a winter season crop with a sowing period from October to December, depending upon the cessation of rains. The crop is ripe within three to four months depending upon the variety and the time of sowing.

Rape (Brassica Napus), Mustard (Brassica Nigra)

Rape and mustard are grown in a variety of soils. It is grown as a mixed crop with wheat, barley, or grain, in the rabi (winter) seasons. It is sometimes grown as a pure crop. The crop is harvested within three months. If sufficient moisture is present, the crop does not require any irrigation.

Linseed (Linum Usitatissimum)

This is a rabi (winter) crop, requiring a well-drained soil with an abundance of available moisture.

DESIGN OF THE SYSTEM

The amount of water to be applied in the field for an efficient irrigation system is determined on the following basis:

(a) Consumptive use of crops to be grown

(b) Expected rainfall

(c) Soil characteristics

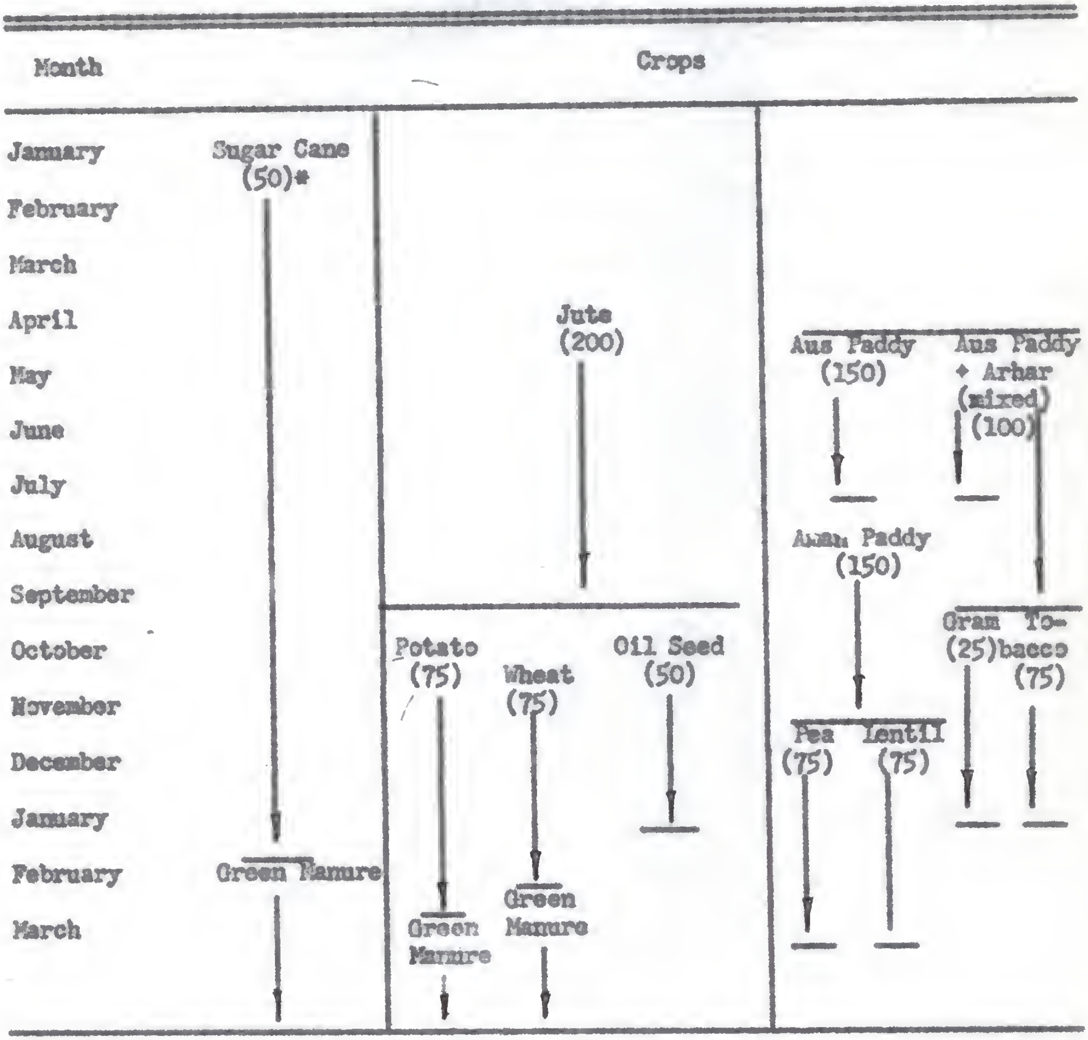
Consumptive use varies from crop to crop and for the same crop at different places. The design values for Indian conditions were taken from Table 4. Rainfall data and soil characteristics were taken from Tables 8, 10 and 11 respectively.

Since the project was designed for the entire West-Bengal, it is not possible to consider all the factors involved specifically. Efforts have been made to include all the possible crops in the model design area and to use a broad range of values so as to make use of the design to any similar project in West-Bengal with little change in the cropping pattern. While doing so the new design discharge should come within the limit of the model design discharge.

A typical crop schedule for the model project is given in Table 12. The schedule includes single, double and tripple cropping. As far as practical the entire area should be divided into different blocks and the crops should be rotated to keep up the fertility of the soil. The block system will also increase the irrigation efficiency. Fertilizer should be used along with the green manuring crop. This will keep a balance between the nutrient uptake and supply.

The lowland area should be used for transplanted Aman Paddy and high land for mixed Aus Paddy and Arhar.

Table 12. Typical Crops Schedule for the Scheme.



*Figures within brackets indicate acreage under each crop.

Determination of Pump Capacity

The selection of the pumps will be based on the maximum design discharge of the system. This can be found by dividing the entire year into different parts according to the crops grown in the field and calculating the design rate for each part. While doing so expected rainfall, crop consumptive use and soil characteristics should be accounted for.

West-Bengal, in general, has two types of soil namely laterite and red soils. They are in the textural group of sandy loam and loam having 1.5 inches available soil moisture characteristics per foot of soil. Assuming four feet of soil available for soil moisture, depth of available soil moisture will be

$=4 \times 1.5 = 6$ inches.

If irrigation water is applied when 50 percent of the available moisture is consumed, the depth of water consumed before irrigation is

$=6 \times 0.5 = 3$ inches.

Depth of soil moisture to be replaced

$=6 \times 0.5 = 3$ inches.

Dividing the entire year into four parts and calculating the water requirements during each period it is possible to determine pump capacity as follows:

Period from Middle of April to Middle of July

Crops in the field	Acreage
Jute	200
Aus Paddy	150
Aus Paddy + Arhar	100
Sugar Cane	50

Average total rainfall during the period = 18 inches.

Average expected rainfall per day = $\frac{18}{90}$ = 0.2 inches.

Since the scheme is for supplementary irrigation, the average values are used. In case of unusual extreme drought condition, the pump will work more hours a day.

For Jute, Aus Paddy and Aus Paddy plus Arhar

Area, A = 450 acres.

Consumptive use = 0.38 inches per day

Irrigation demand

= consumptive use - rainfall

= 0.38 - 0.2

= 0.18 inches per day

$$\text{Irrigation interval} = \frac{\text{depth available}}{\text{irrigation demand}} = \frac{3}{0.18} = 16 \text{ days}$$

Assuming that the pump will work for 20 hours a day, the water to be applied in the field can be calculated from the relationship.

$Qxt = Axd$

Where Q is the discharge in c.f.s.

t is the hours pumped

A is the area in acres

d is the depth of water to be applied, inches

or $Q = \frac{450\text{x}3}{20\text{x}16} = 4.25$ c.f.s. c.f.s. = cubic feet per second.

For Sugar Cane

Area, A = 50 acres

Consumptive use = 0.26 inches per day

Irrigation demand = 0.26 - 0.20

= 0.06 inches per day

Irrigation interval = $\frac{3}{0.06}$

= 50 days

Water to be applied

$$Q = \frac{Axd}{t}$$

$$= \frac{50x3}{50x20}$$

$$= 0.15 \text{ c.f.s.}$$

Total water to be applied

= 4.25 + 0.15

= 4.4 c.f.s.

Since the water will be conveyed to the field through the pipe lines, irrigation efficiency can be assumed to be 75 percent. Under this condition required discharge becomes

$$\frac{4.4}{0.75}$$

5.9 c.f.s.

Total hours pumped during the period

= Hours per day x days per season

= 20x90 = 1800 hours.

Period from Middle of July to End of September

Crops in the field	Acreage
Jute	200
Aman Paddy	150
Arhar	100

Total rainfall during the period = 27.8 inches.

Rainfall per day = 0.38 inches.

Since this rainfall is almost sufficient for the standing crops no irrigation will be given. In case of unusual drought light irrigation may be given according to the need.

Period from October to December

Crops in the field	Acreage
Potato	75
Tobacco	75
Wheat	75
Gram	25
Oil Seed	50
Sugar Cane	50

For Potato and Tobacco

Area, A = 150 acres

Expected rainfall = 0.00 inches

Consumptive use = 0.3 in/day

Irrigation demand = 0.3 in/day

$$\text{Irrigation interval} = \frac{3}{0.3}$$

$$= 10 \text{ days}$$

Assuming that the pumps will run 18 hours a day, water to be applied

$$Q = \frac{Axd}{t}$$

$$= \frac{150x3}{10x18} = 2.5 \text{ c.f.s.}$$

For Wheat

Area, A = 75 acres

Consumptive use = 0.17 in/day

Irrigation demand = 0.17 in/day

Irrigation interval = $\frac{3}{0.17}$

= 18 days

For Gram and Oil Seed

Area, A = 75 acres

Consumptive use = 0.12 in/day

Irrigation interval = $\frac{3}{0.12}$

= 25 days

Water to be applied

$$Q = \frac{Axd}{t}$$

$$= \frac{75x3}{25x18} = 0.5 \text{ c.f.s.}$$

For Sugar Cane

Area, A = 50 acres

Consumptive use = 0.26 in/day

Irrigation interval = $\frac{3}{0.26}$ = 12 days

Water to be applied

$$Q = \frac{Axd}{t}$$

$$= \frac{50x3}{12x18} = 0.685 \text{ c.f.s.}$$

Total water demand during the period

$2.50 + 0.685 + 0.50 + 0.685$

4.37 c.f.s.

Assuming 75 percent irrigation efficiency required pump capacity

$\frac{4.37}{0.75}$

5.85 c.f.s.

Total hours pumped during the period

$18x90$

1620 hours

Period from January to February

Crops in the field	Acreage
Potato	75
Wheat	75
Sugar Cane	50
Pea	75
Lentil	75

Assuming that the pumps will run 12 hours a day, the rate of water to be applied for both potato and wheat will be

$$Q = \frac{Apxd}{tr} + \frac{Awxd}{tw}$$

$$= \frac{75x3}{10x12} + \frac{75x3}{18x12}$$

$$= 1.88 + 1.04$$

$$= 2.92 \text{ c.f.s.}$$

For Sugar Cane

$$Q = \frac{Axd}{t}$$

$$= \frac{50x3}{12x12} = 1.04 \text{ c.f.s.}$$

Total water requirement during the period

$= 2.92 + 1.04$

$= 3.96$ c.f.s.

Assuming 75 percent irrigation efficiency required pump capacity

$$= \frac{3.96}{0.75} = 5.3 \text{ c.f.s.}$$

Pea and lentil generally do not require any irrigation. If the soil is too dry, a light irrigation may be given.

Total hours pumped during the period

$= 12x60$

$= 720$ hours

Period from March to Middle of April

Crops in the field	Acreage
Sugar Cane	50
Green Manure	200

For Sugar Cane

Area, A = 50 acres

Assuming pumps run ten hours a day

$$Q = \frac{Axd}{t}$$

$$= \frac{50x3}{12x10} = 1.25 \text{ c.f.s.}$$

For Green Manure

Area, A = 200 acres

Consumptive use = 0.15

Irrigation interval $= \frac{3}{0.15}$

$= 20$ days

Water to be applied

$$Q = \frac{Axd}{t}$$

$$= \frac{200x3}{20x10} = 3 \text{ c.f.s.}$$

Total water to be applied

= 1.25 + 3.0

= 4.25 c.f.s.

Assuming 75 percent irrigation efficiency pump capacity

$$= \frac{4.25}{0.75}$$

= 5.67 c.f.s.

Hours pumped during the interval

= 10x45

= 450 hours

It has been determined from the above calculations that maximum water demand will occur during the period April to July. The maximum required pump capacity is 6 cubic feet per second. The pump should be selected accordingly.

Pump capacity for the scheme

= 6 cfs

= 6x450

= 2,700 gpm (U.S.)

= 6x64.4x60

= 2,250 gpm (imperial)

Total yearly use of the pump

= 1800 + 1620 + 720 + 450

= 4,590 hours

Pump Work Schedule

Periods	Discharge (cfs)	Hours Per Day
January to February	5.3	12
March to Middle of April	5.67	10
Middle of April to Middle of July	5.9	20
Middle of July to End of September	0.0	0 (if expected rainfall occurs)
October to December	5.85	18

ECONOMIC DISTRIBUTION SYSTEM DESIGN

The layout of the system is shown in Fig. 10. It was assumed that four laterals would work at a time. Under this condition the first part of the main would have a capacity of 2700 gpm, the last part of the main 1350 gpm and each lateral would carry 675 gpm. The economic pipe size was calculated on the basis of minimum annual cost. The ownership cost and the operating costs were estimated in terms of diameter of the pipe. The economic size was then obtained by differentiating and equating the expression to zero.

The following assumptions were made for the calculation:

Total head = pressure head + velocity head + friction head + static lift

or $$H = p/w + \frac{v^2}{2g} + h_f + z$$

Scobey's formula was used to calculate friction losses with constant C_s = 0.316 for concrete pipe and K_s = 0.5 for steel pipe. Williams-Hazan formula with C_1 = 140 was used for asbestos cement pipe while calculating friction losses.

The velocity head is very small and was neglected for the calculation.

Water horsepower, WHP, can be calculated from $WHP = \frac{QH}{3960}$

Where Q is discharge in gpm

H is head in feet

Assuming an overall efficiency of 70 percent the brake horsepower becomes

$$BPH = \frac{WHP}{0.70}$$

Pumping plant initial cost for gasoline fuel

$$l_e = 1517 + 93.44\ WHP$$

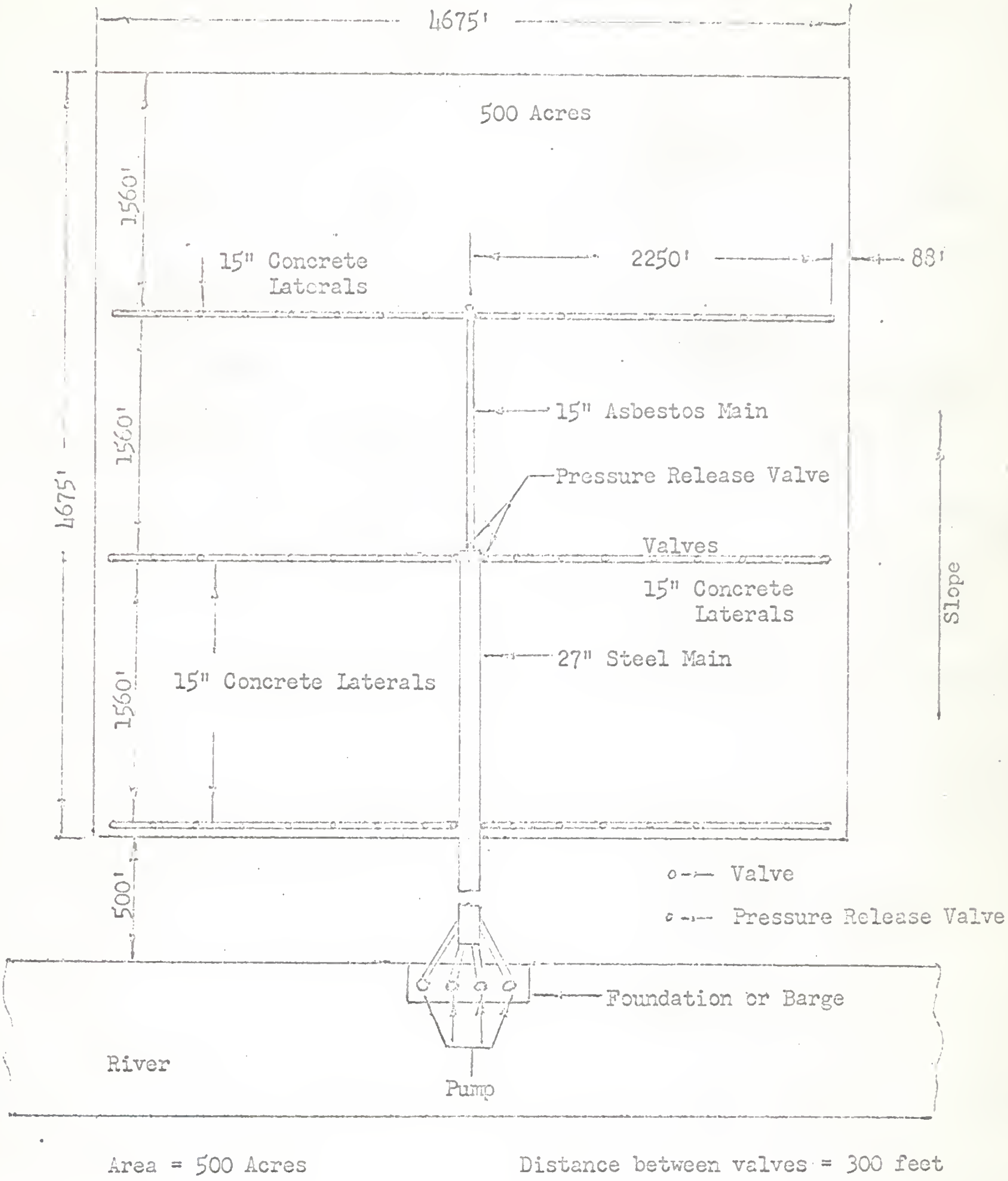


Fig. 10. Schematic Layout of the Economic Distribution System.

Pipe initial cost for L feet

For concrete pipe

$$I_p = 0.77d^{1.16} \times L \text{ in dollars, d is in feet}$$

For asbestos pipe

$$I_p = 3.3d^{1.42} \times L \text{ in dollars}$$

The unit cost diameter relationship for steel pipe was developed on the basis of 20¢ per pound and $\frac{1}{4}$ inch nominal thickness. This gives an initial cost.

$$I_p = 6.4d\ L \text{ in dollars}$$

The annual ownership cost for both pumping plant and pipes was calculated on the basis of 12 percent of the initial cost for 12 years life.

Annual hours of operation = 4590 hours.

Engine develops 9 HP-Hr per gallon of gasoline costing 20¢ per gallon.

Total operating cost = one and one-half times fuel cost.

Laterals

The pressure in the laterals is very low and does not require any high pressure pipe. Since concrete pipe is the cheapest, their use in the laterals will be economical. The flow through each lateral was 675 gpm (1.5 c.f.s.) and the actual length was 2250 feet. An extra length of 750 feet was added for the minor losses making the equivalent length 3000 feet.

Friction loss for 3000 feet

$$h_f = \frac{3v^2}{C_s^2\ di^{1.25}} \qquad di = \text{diameter in inches.}$$

$$= \frac{3(Q/A)^2}{(0.316)^2\ (12d)^{1.25}} \qquad d = \text{diameter in feet}$$

$$= \frac{30\ (1.5)^2}{A^2\ (12d)^{1.25}}$$

$$= 4.9d^{-5.25}$$

Total head loss

$$H = p/w + h_f$$

$$= \frac{15x144}{62.4} + h_f$$

$$= 34.6 + 4.9d^{-5.25}$$

$$WHP = \frac{QxH}{3960}$$

$$= \frac{675}{3960}\ (34.6 + 4.9d^{-5.25})$$

$$= 5.9 + 0.835d^{-5.25}$$

$$BHP = \frac{WHP}{0.7}$$

$$= 8.44 + 1.2d^{-5.25}$$

Pump initial cost

$$l_e = 1517 + 93.44\ WHP$$

$$= 1517 + 93.44\ (5.9 + 0.835d^{-5.25})$$

$$= 2117 + 78d^{-5.25}$$

Pipe initial cost

$$l_p = 0.77d^{1.16} x3000$$

$$= 2310d^{1.16}$$

Annual total ownership cost

$$= 0.12\ (l_e + I_p)$$

$$= 261 + 9.35d^{-5.25} + 277d^{1.16}$$

Annual fuel cost

$$= \frac{BHP}{9} \times 0.2 \times 4590$$

$$= 102 \times BHP$$

Annual total operating cost

$$= 1.5 \times \text{fuel cost}$$

$$= 152 \times BHP$$

$$= = 152\ (8.44 + 1.2d^{-5.25})$$

$$= 1290 + 184d^{-5.25}$$

Total annual cost

$$T_c = \text{Ownership cost} + \text{operating cost}$$

$$\frac{dT_c}{dd} = 1551 + 193.35d^{-5.25} + 277d^{0.16}$$

$$= 1015d^{-4.25} + 322d^{0.16}$$

For minimum, $\frac{dT_c}{dd} = 0$

or $$322d^{0.16}(1 - 3.16d^{-4.41}) = 0$$

or $$d = (3.16)^{0.227}$$

$$= 1.29 \text{ feet}$$

$$= 15 \text{ inches}$$

Hence, 15-inch concrete pipe is most economical.

Total head for 15-inch pipe

$$H = 34.6 + 4.9\ (1.25)^{-5.25}$$

$$= 34.6 + 1.5$$

$$= 36.1 \text{ feet}$$

Total annual cost

$$T_c = 1551 + 193.35\ (125)^{-5.25} + 277\ (1.25)^{1.16}$$
$$= 1551 + 602 + 358$$
$$= 2611 \text{ in dollars}$$

Asbestos Cement Main

In the latter part of the main flow is 1350 gpm (3 c.f.s.). The pressure is quite high along with a chance of water hammer. Concrete pipe is unsafe and steel pipe is too costly. Therefore, high pressure asbestos pipe was used. An extra length of 40 feet was added to the actual 1560 feet pipe to overcome the minor losses making the equivalent length of 1600 feet.

$$h_f = \frac{3020}{C_1 1.85} \times \frac{v1.85}{d^{1.168}} \times 1.6$$

$$= \frac{3020}{(140)^{1.84}} \quad \frac{(Q/A)^{1.85}}{d^{1.168}} \times 1.6$$

$$= \frac{0.322 \times 1.6 \times (3)^{1.85}}{A^{1.85} \times d^{\ 1.168}}$$

$$= 6.14 \times d^{\ -4.868}$$

$$H = p/w + h_f$$

$$= 36.1 + 6.14 \times d^{\ -4.868}$$

$$WHP = \frac{1350}{3960} \times H$$

$$= 12 + 2.09 \times d^{\ -4.868}$$

$$BHP = \frac{WHP}{0.7}$$

$$= 17.15 + 2.99 \times d^{\ -4.868}$$

$$I_e = 15.17 + 93.44 \times WHP$$

$$= 2637 + 195 \times d^{-4.868}$$

$$I_p = 3.3 \times d^{1.42} \times 1600$$

$$= 5280 \times d^{1.42}$$

Annual ownership cost

$$= 0.12\ (I_e + I_p)$$

$$= 316 + 23.5 \times d^{-4.868} + 634 \times d^{1.42}$$

Annual operating cost

$$= 153 \times BHP$$

$$= 2630 + 457 \times d^{-4.868}$$

Total annual cost

$$T_c = \text{ownership cost} + \text{operating cost}$$

$$= 2946 + 480.5 \times d^{-4.868} + 634 \times d^{1.42}$$

$$\frac{dT_c}{dd} = -4.868 \times 480.5 \times d^{-3.868} + 1.42 \times 634 \times d^{0.42}$$

$$= -2360 \times d^{-3.868} + 900 \times d^{0.42}$$

For economic pipe size $\frac{dT_c}{dd} = 0$

or $$900d^{0.42}\ (1 - 2.62d^{-4.288}) = 0$$

or $$d = (2.6)^{0.234}$$

$$= 1.25 \text{ feet}$$

$$= 15 \text{ inches}$$

Hence the economical size is 15 inches.

Total head- $= 36.1 + 6.14\ (1.25)^{-4.868}$

$= 36.1 + 2.07$

$= 38.17$ feet

Total annual cost

$= 2946 + 480.5\ (1.25)^{-4.868} + 634\ (1.25)^{1.42}$

$= 2946 + 163 + 1870 = 3979$, dollars.

Steel Main

Steel pipe would be used in the main to resist high pressure doe to water hammer. To account for the minor losses an extra length of 190 feet was added to the actual length of pipes. This made the equivalent length 2,250 feet. Flow through the main was 2700 gpm (6 c.f.s.).

$$h_f = \frac{0.5 \times 2.225\ v^{1.9}}{d^{1.11}}$$

$$= \frac{1.113\ (Q/A)^{1.9}}{d^{1.1}}$$

$$= 53d^{-4.9}$$

Considering a lift of 30 feet

$$H = p/w + h_f + Z$$

$$= 38.17 + 53d^{-4.9} + 30$$

$$= 68.17 + 53 \times d^{-4.9}$$

$$WHP = \frac{2700}{3960} \times H$$

$$= 46.5 + 36.2 \times d^{-4.9}$$

$$I_e = 1517 + 93.44 \times WHP$$

$$= 7717 + 4530 \times d^{-4.9}$$

$$I_p = 6.4d \times 2250$$

$$= 14400 \times d$$

Annual ownership cost

$$= 0.12\ (I_e + I_p)$$

$$= 925 + 544 \times d^{-4.9} + 1730 \times d$$

Annual operating cost

$$= 153 \times BHP$$

$$= 10200 + 7920 \times d^{-4.9}$$

Total annual cost

$$T_c = 11{,}125 + 8464d^{-4.9} + 1730 \times d$$

For economic pipe size

$$\frac{dT_c}{dd} = 0$$

or $$-4.9 \times 8464d^{-3.9} + 1730 = 0$$

or $$d = (24)^{0.257}$$

$$= 2.26 \text{ feet}$$

$$= 27 \text{ inches}$$

Hence the economic main steel pipe size is 27 inches.

Total head

$$H = 68.17 + 53 \times (2.25)^{-4.9}$$

$$= 69.17 \text{ feet.}$$

Total head developed by the pump

$$H_p = H - p/w$$

$$= 69.17 - 34.6$$

$$= 34.57 \text{ feet}$$

Total cost

$$T_c = 11{,}125 + 8464\,(2.25)^{-4.9} = 1730 \times 2.25$$

$$= 11{,}125 + 160 + 3900$$

$$= 15{,}185, \text{ dollars.}$$

DISTRIBUTION SYSTEM DESIGN ON THE BASIS OF MATERIALS AVAILABLE IN INDIA

The choice of the material for the distribution system is very limited, at present, in India. Different pipe sizes with different materials are not readily available for economic distribution system design. Smaller pipes are being used at the expense of head losses and consequently larger pumping plant size and higher operating costs are involved.

In a similar design nine-inch cement-concrete pipes are mostly used for the laterals. In the most favorable condition when all the laterals work together, the flow in each one of them is 450 gpm (1 c.f.s.). Total head to be developed at the beginning of the laterals for equivalent length of 3000 feet is

$$H = \frac{p}{w} + \frac{v^2}{2g} + h_f$$

$$= \frac{15 \times 144}{62.4} + \frac{(2.275)^2}{64.4} + \frac{v^2}{C_s^2 \; di^{1.25}} \times \frac{L}{1000}$$

$$= 34.6 + 0.08 + \frac{3v^2}{(0.316)^2 \; di^{1.25}}$$

$$= 34.68 + 9.94$$

$$= 44.62 \text{ feet}$$

Equivalent pressure head = 19.4 psia.

In some designs, the first few hundred feet of the lateral have been replaced by six-inch asbestos cement pipe. From Fig. 6, it is determined that for 450 gpm flow the head loss for 1000 feet pipe is 15 feet which is five times greater than that of nine inches concrete pipe. Due to crop demand if flow exceeds more than 6 c.f.s., the loss of head due to friction would be tremendously high.

From similar reasoning use of six-inch asbestos pipe in the last part of the main is undesirable. However, a nine-inch asbestos cement pipe can be used. Considering 900 gpm (2 c.f.s.) flow, the total head to be developed at the beginning of the asbestos main,

$$H = \frac{p}{w} + \frac{v^2}{2g} + h_f$$

$$= 44.62 + 0.32 + 15.70$$

$$= 60.64 \text{ feet}$$

Equivalent pressure head = 26.2 psia.

For the main pipe 12.75 inch steel pipes are commonly used. In the first part of the main there is a flow of 2700 gpm (6 c.f.s.). After the first laterals the flow reduces to 1800 gpm (4 c.f.s.). If larger diameter pipes are available, it should be used in the first part of the main as indicated by the economic design. Considering 12.75 inch steel pipe for the entire main, total head to be developed at the first lateral

$$H = \frac{p}{w} + \frac{v^2}{2g} + h_f$$

$$= \frac{p}{w} + \frac{v^2}{2g} + \frac{K_s \times 1600}{1000} \frac{v^{1.9}}{d^{1.1}}$$

$$= 60.64 + 0.32 + 0.5 \times 1.6 \frac{v^{1.9}}{d^{1.1}}$$

$$= 60.96 + 13$$

$$= 73.96 \text{ feet}$$

Equivalent pressure head = 32 psia.

Considering lift of 30 feet, total dynamic head for the pump

$$H = \frac{P_1}{w} + \frac{v^2}{2g} + \frac{K_s \times 650}{1000} \frac{v^{1.9}}{d^{1.1}} + 2 \frac{P_a}{w}$$

$$= 73.96 + 0.7 + 11.6 + 30 - 34.6$$

$$= 116.26 - 34.6$$

$$= 81.66 \text{ feet.}$$

Equivalent pressure head for the pump = 50 psi.

$$WHP = \frac{QH}{3960}$$

$$= \frac{2700 \times 81.66}{3960}$$

$$= 55.7$$

$$BHP = \frac{WHP}{0.7}$$

$$= \frac{55.7}{0.7}$$

$$= 79.6$$

$$= 80.0$$

For the above mentioned condition, the engine should develope 80 hp and the pump capacity should be 2700 gpm (6 cfs) at 81.66 feet of total head.

In India such big units are not commonly manufactured for this purpose at present. In a similar project, the Agricultural Engineering department of West-Bengal installs four small units for a single scheme. The most commonly used type of pump and engine has the following specifications.

Name: Kirloskar Diesel Engine

Type: B2

BHP: 20

RPM: 1500

Pump Capacity:				
	Head ft:	40	50	60
	GPM: (imperial)	700	650	550
	GPM: (U.S.)	840	780	660

As regards power the selection is allright. The pump capacity is little less at the required head. The assumed 30 foot lift is on the upper side. Therefore, the pumps would be in a position to supply the required water.

Installation:

In West-Bengal water can be pumped either from rivers or from beels (lakes). In rivers, fluctuations of the water level is too great. Steel barges are used for installation in such rivers. The water level in beels does not vary too much. A concrete foundation with two horizontal bases, one for summer and the other for winter should be constructed in beels. Arrangement should be made for easy and quick lifting and lowering of the pumps and engines. A shed must be provided to save the pumps and engines.

As regards topography neither of the two schemes would be similar. Specific distribution system layout is not possible for any system without a

contour map. Since leveling is not generally done, the distribution system should follow the ridges in the field as far as possible. On the river bank, the general slope is away from the bank. A model distribution system layout with different pipe sizes is shown in Fig. 11.

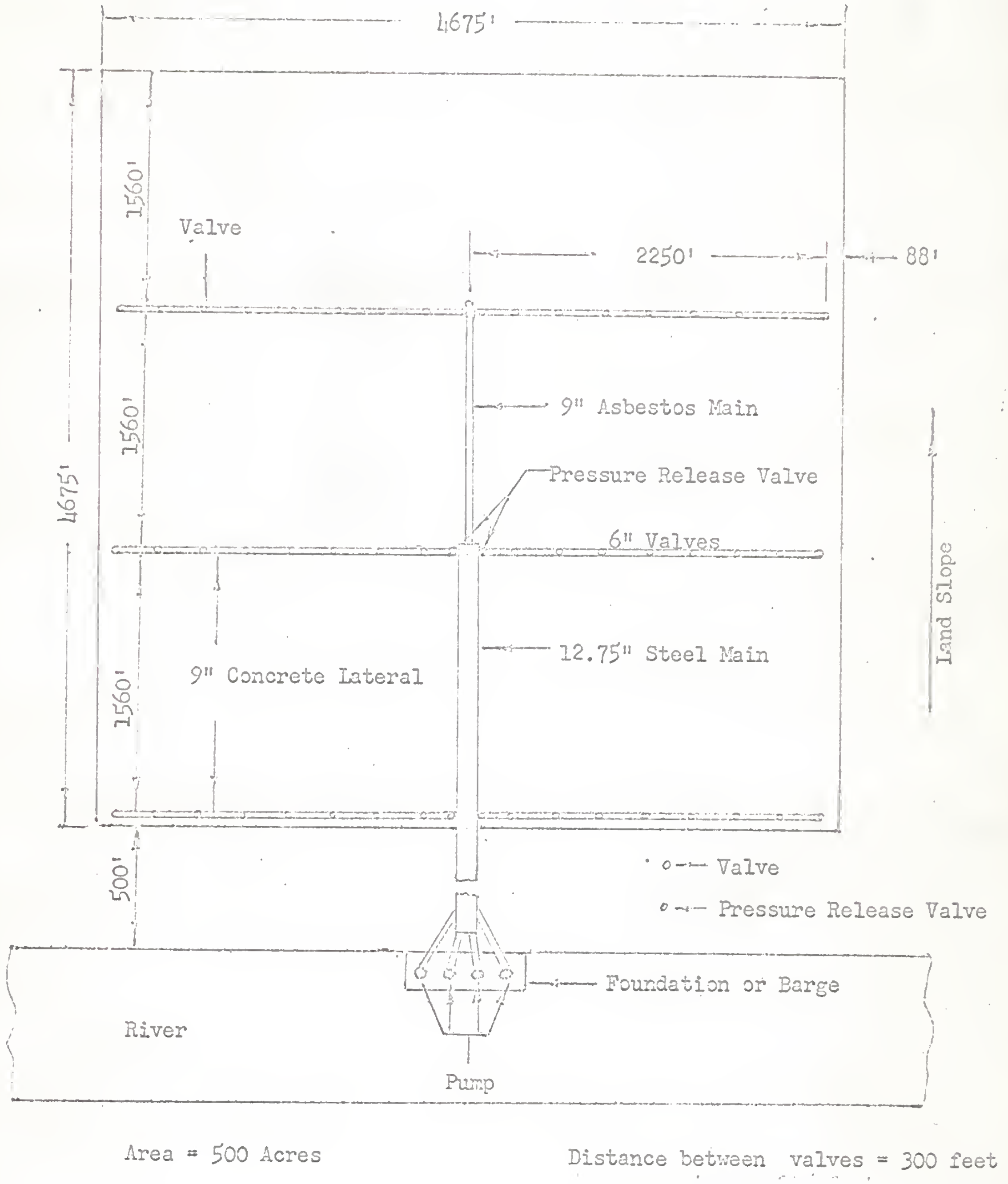


Fig. 11. Schematic Layout of the Model Distribution System.

COST ANALYSIS

The cost analysis will be made on the design that is used at present in India so as to get an idea about the costs involved.

For convenience, the total cost per unit is broken down into (1) ownership and (2) operating costs.

Ownership costs:

They are those which are usually not directly related to the amount of use and include:

1. Depreciation
2. Interest on investment
3. Housing
4. Taxes and insurance

Operating costs:

They are directly related to use and include:

1. Fuel
2. Lubricants
3. Repair and maintenance
4. Labor.

While estimating the costs the prevailing costs of different materials in India in terms of rupees (one dollar = seven and one-half rupees) will be used. The final value will also be shown in terms of dollars.

The following are some of the assumptions which will be used for the estimation:

Depreciation: straight line method

Pumping plant life: 12 years

Life of pipe line: 15 years

Barge or foundation life: 20 years

Life of shelter: 30 years

Salvage value is assumed to be nil.

Interest: one half the new cost basis

Rate: four percent

Taxes: no taxation

Insurance: generally not done

Fuel:

Annual operation: 4590 hours

Fuel used: diesel

Consumption: 0.3 liters per hp-hr

Costs: Rs.0.60 per liter

Lubricant: 0.4 percent of initial cost

Repair and maintenance:

Pumping plant: 3.5 percent of initial cost

Pipe line: 1 percent of initial cost

Shelter: 1 percent of initial cost

Barge or foundation: 0.5 percent of initial cost

Labor:

Operator: Rs.175 per month

Assistant operator: Rs.100 per month

Initial cost:

Item 1. Cost of pump and engines including transportation and accessories.

@ Rs. 13000 per set

= 4 + 13000 = Rs. 52000

Item 2. Cost of pipe including transportation and installation.

a. steel main: (12.75 inches dia)

length = 2060 feet @ Rs. 25 per foot

= Rs. 25 x 2060

= Rs. 52000

b. asbestos main: (9 inches dia)

length = 1560 feet @ Rs. 15 per foot

= Rs. 1560 x 15

= Rs. 23400

c. cement concrete laterals: (9 inches dia)

length = 6 x 2250 feet @ Rs. 750 per foot

= Rs. 7.50 x 6 x 2250

= Rs. 101400

d. miscellaneous fittings

= Rs. 2200

Total cost = 52000 + 23400 + 101400 + 2200

= Rs. 179000

Item 3. Cost of steel barge or concrete foundation with shed.

= Rs. 28000

Item 4. Cost of land and shelter for operator and assistant operator.

= Rs. 12000

Fuel cost:

= Rs. 0.3 x 4 x 20 x 0.60 x 4590

= Rs. 6,600

Item	Pumps(1)	Pipes(2)	Barge(3)	Shelter(4)
Annual cost of ownership, Rs.				
Depreciation	4,340	6,760	1,400	400
Interest on investment	2,028	1,040	560	240
Total Annual ownership cost	6,368	7,800	1,960	640
Total Annual ownership cost of all item			= Rs. 16,768 = ($2,235)	
Annual cost of operation, Rs				
Fuel	6,600			
Lubricant	208			
Repair and maintenance	1,820	1,104	140	120
Labor	3,300	—	—	—
Total Annual cost of operation	11,928	1,104	140	120
Total Annual operating cost of all item			= Rs. 13,292 = ($1,765)	

Total annual cost = Rs. 16,768 + Rs. 13,292

= Rs. 30,060 ($4,000)

Annual cost per acre = Rs. 60.00

= $8.00

CONCLUSION AND RECOMMENDATION

The model design was based on the general crop, soil and climatic conditions of West-Bengal. In general, the deviation of the variables for any specific design might not be far away from that used in the model design and, therefore, the same design would serve the purpose for most of the schemes. In case of large deviations, a new cropping pattern, suitable for the place, should be prepared and the design discharge should be recalculated. Even in that case the new design discharge might be kept within the limit by changing the hours of operation of the pumps, if necessary.

It has been found that the pumps should run a maximum of 20 hours a day during the first Kharif crop. This would force the operator as well as the farmers to work at night. But considering the scarcity, need and economy, proper arrangements should be made to convince both the operator and the farmers to work at night during the peak period. If the number of hours is reduced, it is not possible to irrigate 500 acres with 2700 gpm discharge, as is practiced at present in West-Bengal. The schemes are mainly for supplimentary irrigation and if usual rainfall occurs, the daily hours of operation may be reduced considerably.

The design of an economic distribution system and the system followed, at present, in West-Bengal showed that there was a considerable wastage of power and consequently loss of money every year due to extra head loss in the smaller size of pipes. Since this extra loss is quite high, emphasis should be given to the manufacture of special larger pipes for this purpose. Due to the higher demand, the production cost may not go up for such pipe sizes.

Cost analysis showed that the annual expenditure is about 60 rupees per acre which should be realized from the farmers in the form of taxation. Most

of the schemes are still under the phase of installation and not in a position to irrigate 500 acres with such a cropping pattern. It would be an injustice to the farmers to collect the full tax if water does not reach their fields according to their needs. Moreover, the farmers should realize the utility of the double or triple cropping before they are heavily taxed. The first few years free water with gradual taxation seems to be the best for Indian conditions.

Irrigation water is not free as rainwater. As far as practical, proper utilization of every single drop of water should be made. The operator must be given a basic training for water use. The extension worker must work hard with the farmers to train them for the proper utilization of water. As far as possible the entire area should be divided into different blocks and the farmers of each block should follow some cropping pattern. Agricultural Engineers, who are in charge of such projects should try their best to convince the farmers to follow some cropping pattern and they should prepare the irrigation schedule accordingly. Proper records should be maintained in each scheme which would help in preparing future schedules. The success of the schemes depends entirely on the co-ordination between the farmer, extension and engineering personnels. Emphasis should be given on this aspect.

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The author would consider his work worthwhile if this report can be of any assistance in implementing river irrigation schemes in India and particularly in West-Bengal.

Hirendra Nath Haldar

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APPENDIX-A

METRIC CONVERSIONS, ILLUSTRATIONS AND TABLES

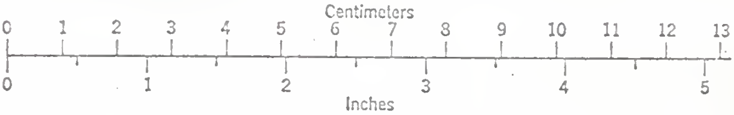
Table A_1. American--English-Metric Conversions Constants.

Length and Distance	Inches	Feet	Yards	Statute Miles	Nautical Miles	Centi-meters	Meters	Kilo-meters
one inch equals	1	.083	.027	—	—	2.54	—	—
one foot	12	1	.333	—	—	30.48	.305	—
one yard	36	3.0	1	—	—	91.44	.914	—
1 statute mile	—	5280	1760	1	.865	—	1609	1.61
1 nautical mile	—	6080	2027	1.15	1	—	1853	1.85
1 centimeter	.394	.0328	.0109	—	—	1	.01	—
1 meter	39.37	3.281	1.094	—	—	100	1	.001
1 kilometer	—	3281	1094	.6214	.5396	—	1000	1

USEFUL APPROXIMATIONS: 5 cm. = 2 in.; 10 cm. = 4 in.; 30 cm. = 1 ft.; 10 meters = 33 ft.; 10 km. = 6 miles; 16 km. = 10 miles; 1 fathom = 6 ft.; 120 fathoms = 1 cable length.

Areas	Square Inches	Square Feet	Square Yards	Acres	Square Centimeters	Square Meters	Hectares
1 sq. inch	1	.007	—	—	6.45	.00064	—
1 sq. ft.	144	1	.1111	—	—	.0929	—
1 sq. yd.	1296	9	1	—	—	.8361	—
1 acre	—	43560	4840	1	—	4050	.405
1 sq. cm.	.155	—	—	—	1	.0001	—
1 sq. m.	1550	10.76	1.20	—	10.000	1	.0001
1 hectare	—	107.600	11.955	2.47	—	10.000	1

USEFUL APPROXIMATIONS: 1 hectare = 2½ acres; 1 sq. in. = 6½ sq. cm.; 1 sq. m. = 11 sq. ft.; a hectare is 330 feet on each side.



Volume and Capacity	Cubic Inches	Cubic Feet	American Gallons	Imperial Gallons	Cubic Meters	Liters	Quarts
1 cu. inch	1	.00057	.0043	.0035	—	.0163	.0173
1 cu. foot	1728	1	7.48	6.23	.0283	28.3	29.9
1 Am. gallon	231	.134	1	.833	.0038	3.78	4
1 Imp. gallon	277.4	.161	1.201	1	.0045	4.55	4.8
1 cu. meter	61030	35.3	264.2	220	1	1000	1057
1 liter	61.03	.0353	.264	.220	.001	1	1.057

USEFUL APPROXIMATIONS: 16.4 cc. = 1 cu. in.; 35 cu. ft. in a cu. m.; 1 register ton = 100 cu. ft.; 1 U.S. shipping ton = 40 cu. ft. or 32.14 U.S. bushels or 31.14 Imp. bu.

Weights	Grains	Grams	Ounces (avoir.)	Pounds (avoir.)	Kilos	Short Ton	Long Ton	Metric Ton
1 grain	1	.0648	.0023	.00014	—	—	—	—
1 gram	15.4	1	.035	—	—	—	—	—
1 ounce	437.5	28.35	1	.0625	.0283	—	—	—
1 pound	7000.—	454.—	16	1	.4536			
1 kilogram	15432.	1000.	35.27	2.205	1	—	—	—
1 short ton	—	—	—	2000.—	907.	1	.893	.907
1 long ton	—	—	—	2240	1016	1.12	1	1.016
1 metric ton	—	—	—	2205	1000	1.102	.984	1

AIR PRESSURE: In terms of atmospheres—One atmosphere equals 14.7 pounds per sq. in. or 1.033 kilo per square centimeter. Normal tire pressure is 2 atmospheres = 29 lbs./sq. in.

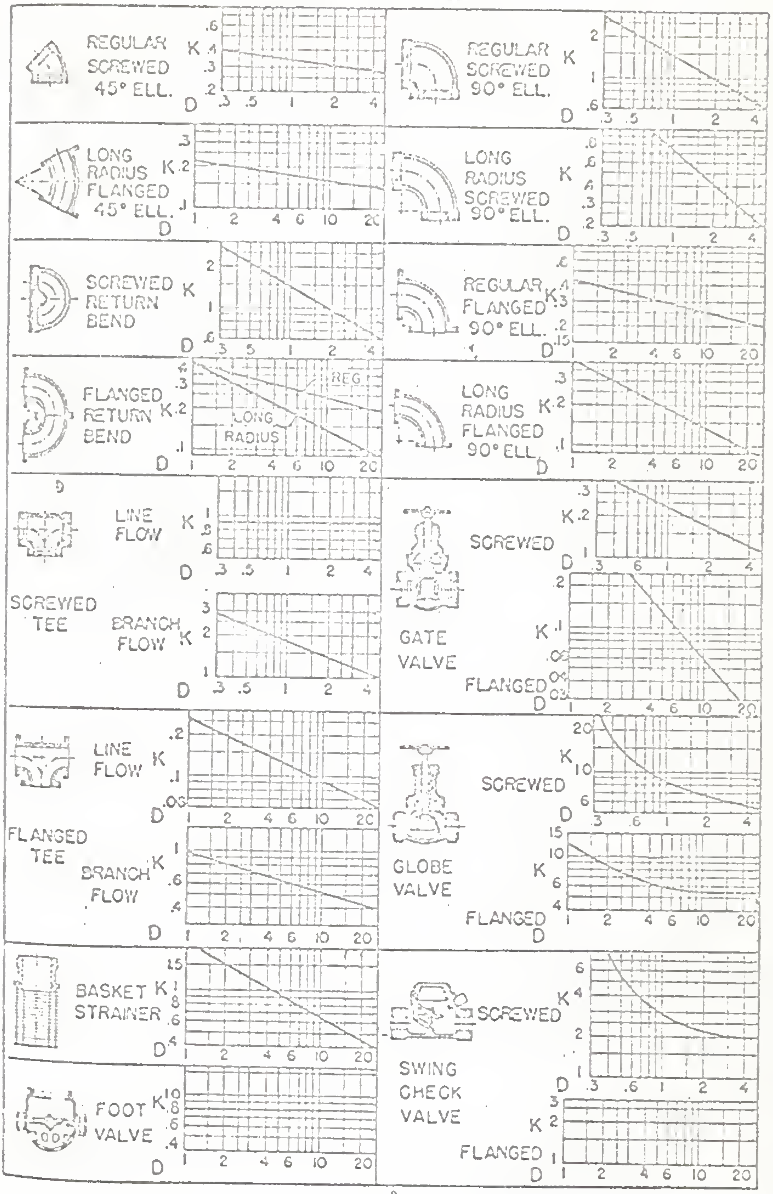
Source: Israelem (14)

Table A_2. Resistance of Fitting and Valves.

(length of straight pipe, feet, giving equivalent resistance)

Pipe size, in.	Standard ell	Medium-radius ell	Long-radius ell	45-deg ell	Tee	Gate valve, open	Globe valve, open	Swing check, open
1	2.7	2.3	1.7	1.3	5.8	0.6	27	6.7
2	5.5	4.6	3.5	2.5	11.0	1.2	57	13
3	8.1	6.8	5.1	3.8	17.0	1.7	85	20
4	11.0	9.1	7.0	5.0	22	2.3	110	27
5	14.0	12.0	8.9	6.1	27	2.9	140	33
6	16.0	14.0	11.0	7.7	33	3.5	160	40
8	21	18.0	14.0	10.0	43	4.5	220	53
10	26	22	17.0	13.0	56	5.7	290	67
12	32	26	20.0	15.0	66	6.7	340	80
14	36	31	23	17.0	76	8.0	390	93
16	42	35	27	19.0	87	9.0	430	107
18	46	40	30	21	100	10.2	500	120
20	52	43	34	23	110	12.0	560	134
24	63	53	40	28	140	14.0	680	160
36	94	79	60	43	200	20.0	1,000	240

Source: Hicks (12)



*Courtesy of Hydraulic Institute. $h = k\frac{v^2}{2g}$ feet of fluid.

Fig. A_1. Resistance Coefficients for Pipe Fittings.

Source: Hicks (12)

To use: 1. Select appropriate values on scales A, B, D and F.
2. Place a ruler *from* the point on scale A, *through* the point on scale B, to the first pivot line, scale C.
3. Place the point of a sharp pencil against the ruler on the pivot line, slide the rule on the pencil *through* the point on scale D *to* the second pivot line, scale E.
4. Repeat step 3, pivoting on E, passing *through* the point on F *to* G.
5. Read the answer on G.

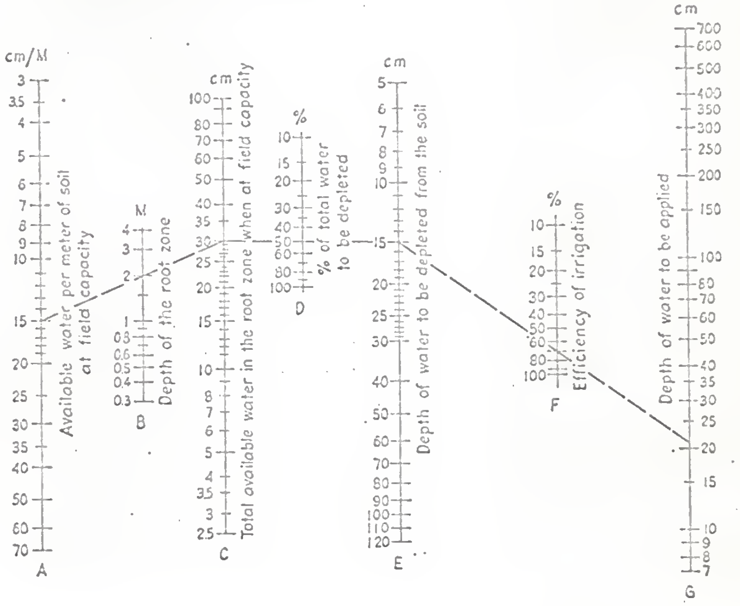


Fig. A_2. Calculating Depth of Water to be Applied per Irrigation.

Source: Israelsen (14)

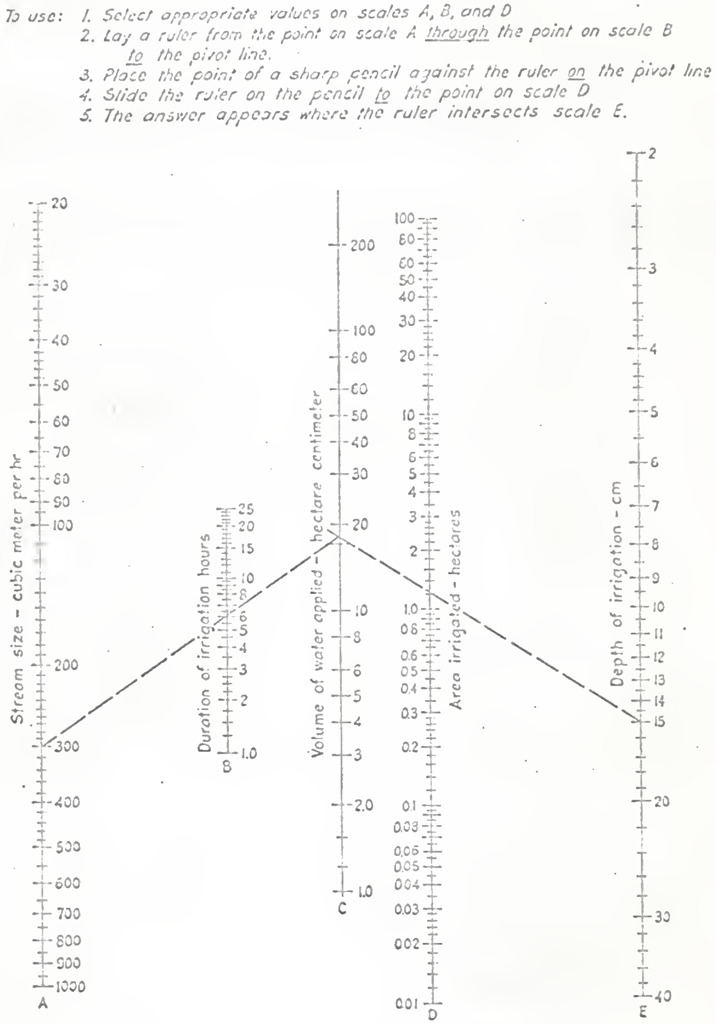


Fig. A_3. Relation Between Stream Size, Time of Irrigation and Depth of Water to be Applied. qt = Ad

Source: Israelsen (14)

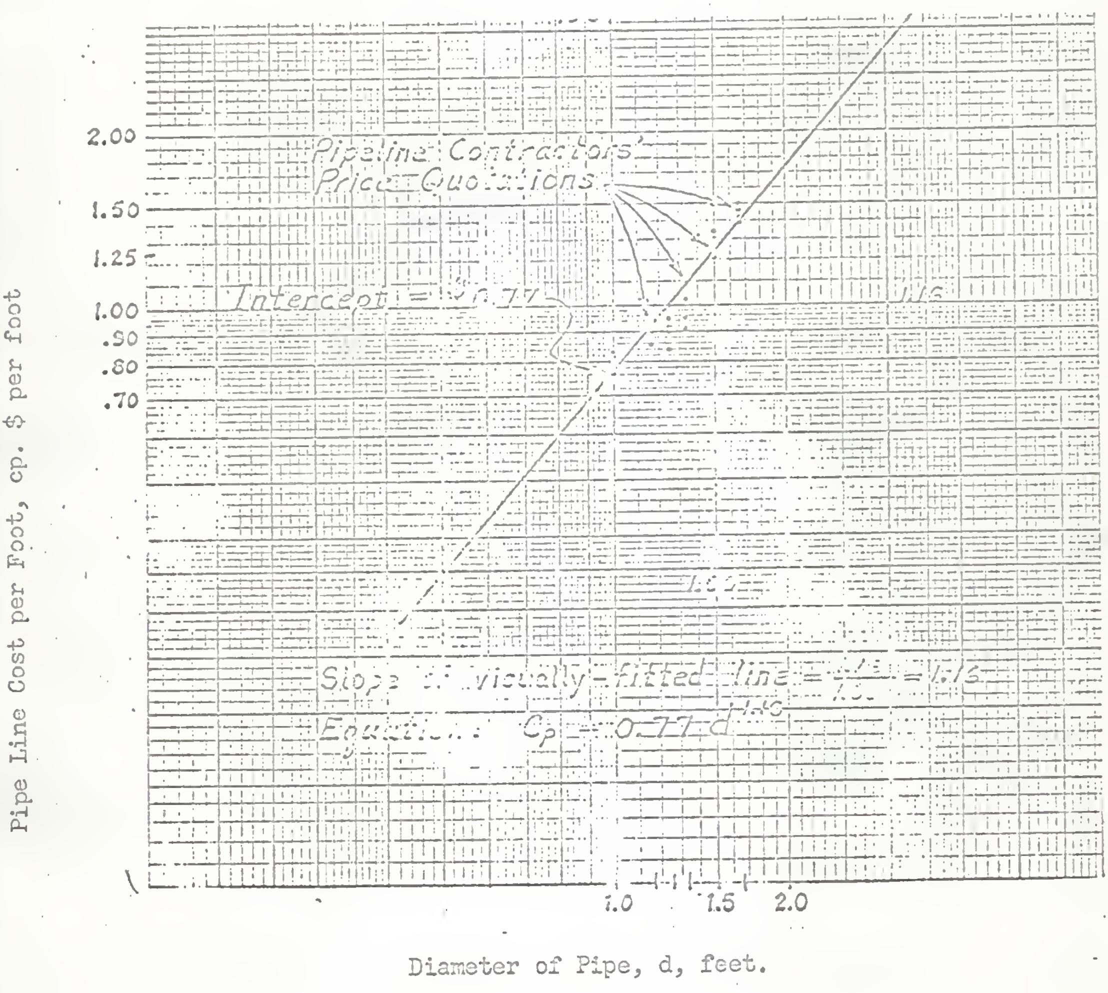
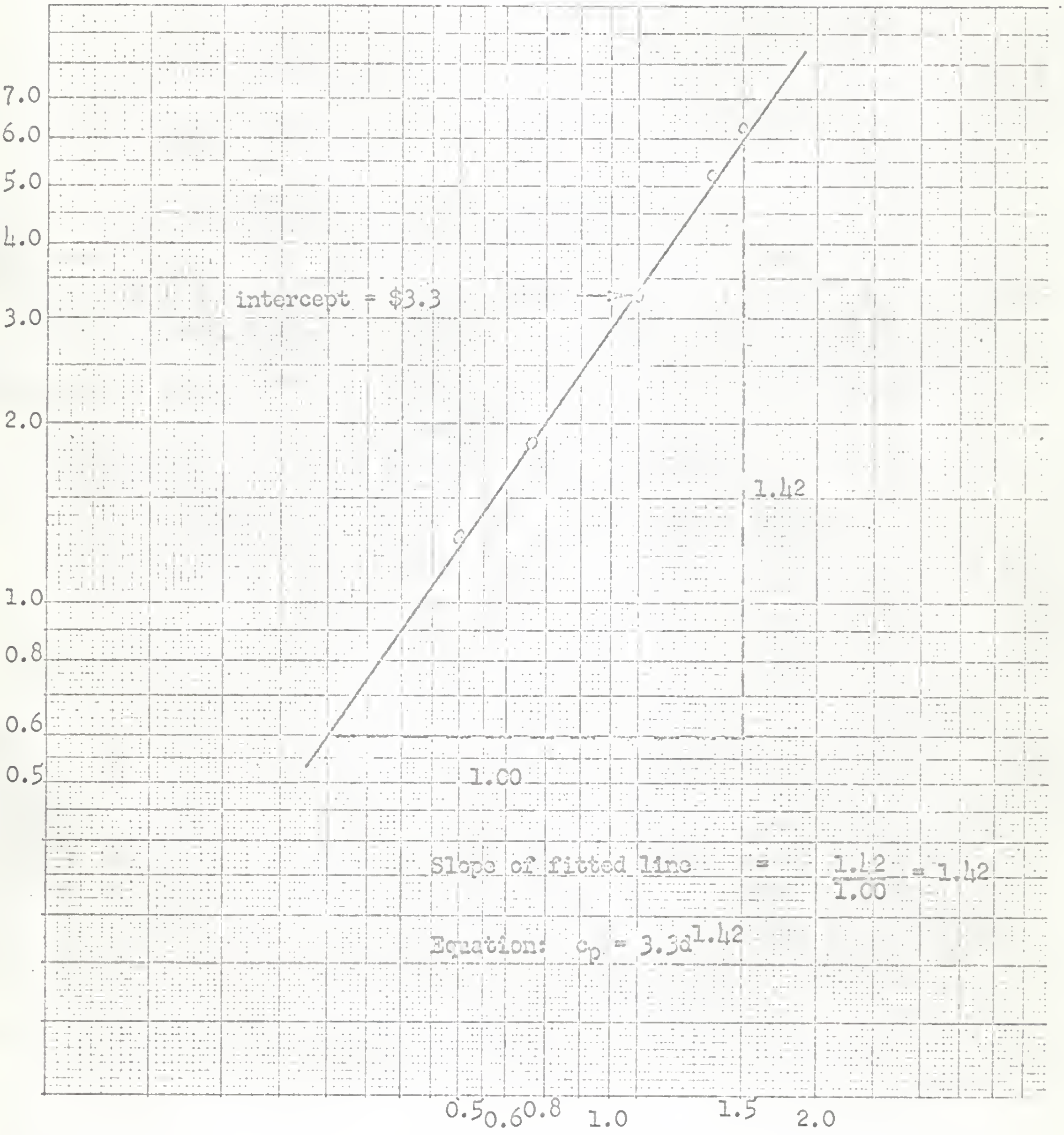


Fig. A_4. Installed Cost per Foot as a Function of Pipe Diameter for Concrete Irrigation Pipe Line.

Source: Horn (13)



Diameter of Pipe, d, in feet

Fig. A5. Installed Cost per Foot as a Function of Pipe Diameter for Asbestos Cement Pipe.

(Price supplied by Extension Engineering Department, Kansas State University)

MODEL RIVER LIFT IRRIGATION SCHEME FOR INDIA

by

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Food shortage has become an acute problem in India for the last few years. The continuous drought that was prevailing in India for some years has made the situation worse. India, being an agricultural country, must attain self sufficiency in food for its survival. During the third Five Year Plan considerable importance has been given to increase the production of food grains with the application of improved varieties of seeds and fertilizer. Irrigation is gaining importance to save the crops from monsoon failure. Besides the use of ground water and surface water through canal system, there is a promising scope of utilization of surface water for irrigation through small lift irrigation schemes. Several hundred million acre-feet of surface water, where construction of dam is not economically feasible, can be utilized through such systems. Considerable thought has been given to the subject and the work for such a scheme is under progress in West-Bengal.

The purpose of this report was to design a 500 acre model river lift irrigation scheme for West-Bengal conditions. The design was based on the water requirement of crops, soil characteristics and climatic conditions. Varieties of crops were included in the model scheme with double and tripple cropping possibilities. Although a specific design was not possible for entire West-Bengal, the model design would help in arriving at a specific design with little change in the cropping pattern and other design parameters, if necessary.

To design for the required discharge of the system, a suitable crop schedule with representative crops was prepared. The entire year was divided into different segments according to the crops growing in the fields and their ages. Average design discharge was calculated for each segment. The pump was selected on the basis of maximum discharge that was required for each segment.

Since the system would work as a supplimentary irrigation supply over the usual rainfall, average values were taken in the design. In case of unusual drought condition the pump would run more hours to supply the demand. Maximum discharge of 2700 gpm (6 c.f.s.) was found to occur during the period from middle of April to middle of July. During the same period the pump should run 20 hours a day. The annual hours of operation was calculated to be 4590 hours.

The economic distribution system was then designed for the entire system on the basis of existing price of different pipes in the U. S. A. Twenty-seven inch steel pipe was found to be economical for the first part of the main where the flow was 2700 gpm. In the latter part of the main where the flow was 1350 gpm fifteen inch high pressure cement asbestos pipe was economical. On the assumption that four laterals would work together, each having a flow of 675 gpm, 15 inch [illegible] ete pipe was calculated to be economical for the lat [illegible]

The distribution system was then redesigned on the basis of the materials available in India. Since larger pipes are not available, it was assumed that all six laterals would work simultaneously. Sacrificing some head losses it was decided to use 12.75-inch steel pipe in the first part of the main and nine-inch high pressure asbestos pipe in the latter part of the main. Nine-inch cement concrete pipe was used in the lateral. Considering 30 foot lift, the total head the pump should develop was found to be 81.66 feet. A total BHP of 80 must be supplied by the engine. These requirements were found to be almost within the limiting value of the pumps working in West-Bengal.

Cost analysis was then made on the basis of existing prices in India. Total annual cost was found to be Rs 30,060 ($4,000) for the entire 500 acres. This gave an annual cost of Rs 60 ($8.00) per acre which would eventually be collected from the farmers in the form of taxation.